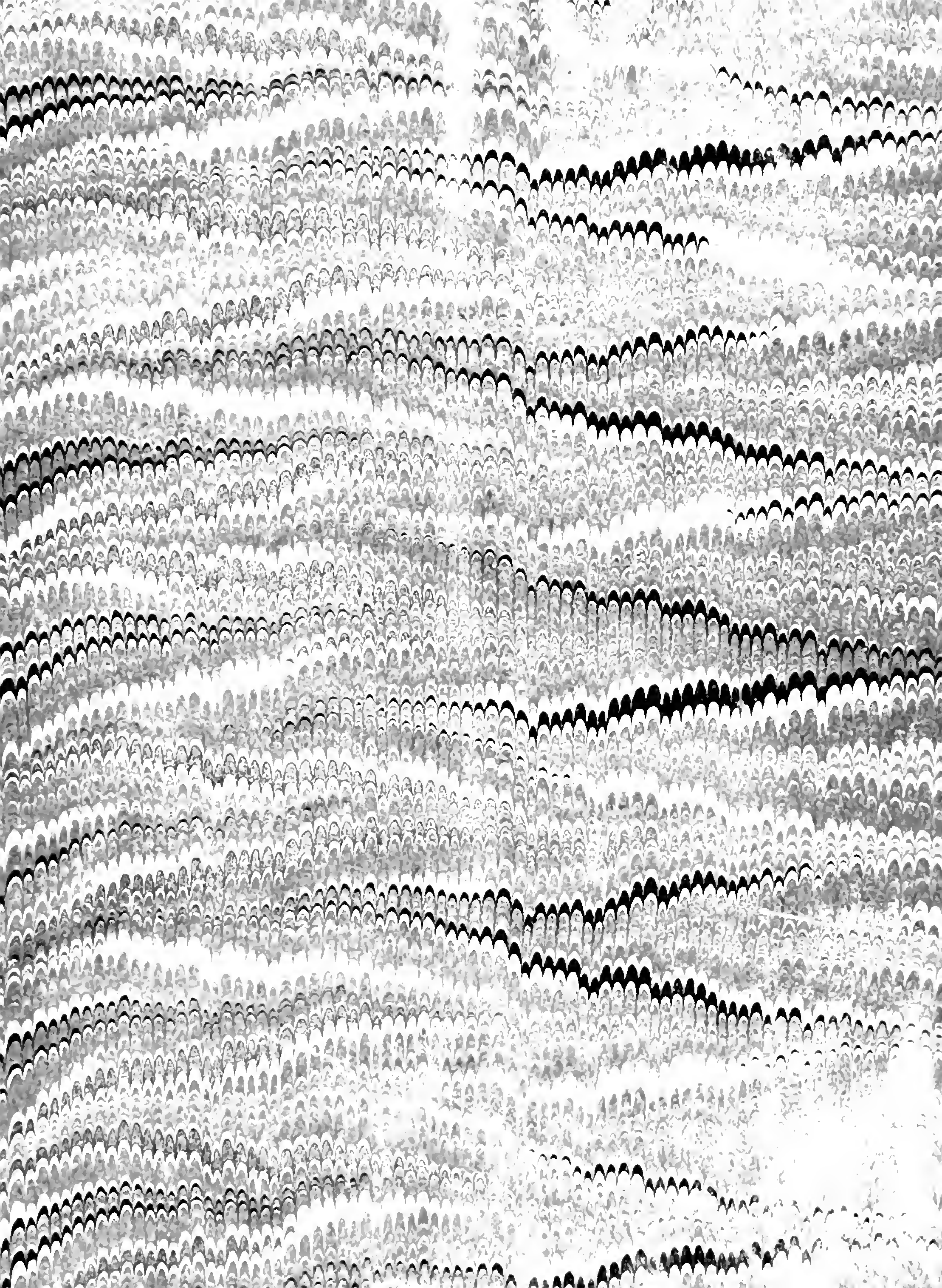

A DETERMINATION OF THE HEAT OF FUSION OF ICE.

By

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INTRODUCTION.

At the present time there is no constant of nature of greater importance, and at the same time less well known, than the heat of fusion of ice. One naturally refers to the classic researches of Regnault, and to the later determination of Bunsen as fully determining this constant. But a comparison of the values obtained by these two investigators shows that they differ by 1 part in 100, and a more critical examination of the original memoirs is sufficient to convince one that neither determination is all that could be desired. Determinations made by other investigators, while agreeing well among themselves, give results which differ considerably from each other. At the present time it is safe to say that the heat of fusion of ice is known only to 1 part in 200. This wide variation was pointed out three years ago by Professor J.S.Ames

Paris Reports, 1900. vol.I. p.178.

in his paper on the Mechanical Equivalent of Heat, and at that time he suggested to the writer the need of a more exact determination of this constant. It was not until the present year, however, that it was possible to take up this investigation and carry it through.

The whole subject of calorimetry must be regarded as still in its infancy as long as its measurements are expressed in variable and unknown units. The usual unit employed, viz., the gram-degree calorie can never

become a satisfactory standard for the measurement of quantities of heat inasmuch as it involves the measurement of changes in temperature of some substance and all the inherent uncertainties connected with such measurements. This is doubly true when the substance employed has a varying heat capacity, as is the case with water. A far more satisfactory unit would be one expressed in terms of the heat required to produce a change of state without any attendent change of temperature. The most convenient unit for practical purposes and fulfiling these conditions, is found in the heat of fusion of ice, and it is surprising that no determination of this very important constant has been attempted for a third of a century, and that no electrical method has ever been used.

Electrical measurements have now attained such a degree of perfection that the heat generated by an electric current can be determined with an accuracy far surpassing any direct calorimetric method. The problem which I have undertaken to solve is the determination of the heat of fusion of ice in terms of the electrical units.

PREVIOUS DETERMINATIONS.

The fact that when heat is given to a piece of ice its temperature is raised until 0°C. is reached, at which point it remains while large quantities of heat continue to be added, was first pointed out by Black[1] in his remarkably clear and explicit lectures on chemistry delivered in Edinburgh in 1762. The heat which was thus used in melting the ice without producing any change in temperature was called by him "latent heat," a name which, altho not altogether felicitous, has clung to it ever since.

Black determined the amount of this "latent heat" by several methods. In one experiment he measured the time required for the conversion of a known quantity of ice at 32°F. into water at 40°F. in a room of which the temperature remained constantly at 47°F., and compared it with the time during which the temperature of an equal weight of water rose under similar circumstances from 32°F. to 40°F. He thus obtained for the heat of

[1] Black, Lectures on Chemistry, vol. I, pp. 120 - 127.

fusion of ice the number 139°F. In another experiment 119 parts of ice at 32°F. were melted in 135 parts of water at 190°F. giving 254 parts of water at 53°F. Hence taking into account the different specific heats of the water and the containing vessel, he deduced the number 143°F. In a third experiment, which is really a modification of the last, the water was warmed to 178°F. and mixed with an equal weight of ice. The resulting mixture was water at 32°F., giving for the heat of fusion the number 144°F. The last two methods are much more accurate than the first, and give the mean value 143.5°F. or 79.7 C.

A few years later Wilke, a Swede, determined the heat of fusion of ice by a different method. He took two similar vessels, one filled with water at 0°C., and the other with an equal weight of snow at the same temperature, and placed them both in boiling water. When the thermometer in the first vessel reached 72°C. he quickly removed the second, assuming that it had received the same amount of heat as the first. The temperature indicated was +2°C. and a bit of the snow was unmelted.

This soon melted, reducing the temperature to 0 C., and therefore Wilke took the number 72 as representing the heat of fusion of the snow. The inherent errors of this method are so great, the wonder is that they balance each other as nearly as they appear to do.

The first determination of the heat of fusion of ice worthy the name was made in 1780 by Laplace and Lavoisier.[1] In their work on specific heats they used an ice calorimeter consisting of an inner chamber surrounded on all sides by finely broken ice. This ice was protected from outside heat by another covering of ice. A warm body placed within the chamber would melt some of the surrounding ice, the resulting water being allowed to drain away to where it was collected and measured. Equal weights of different substances, when warmed to the same temperature and placed within the calorimeter, were found to melt different amounts of in cooling to 0°C. By comparing the amounts of ice thus melted the relative specific heats of different substances were obtained.

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[1] Lavoisier et Laplace. Memoires de l'Academie des sciences 1780. p.355.
Oeuvres de Lavoisier. t.I. p.283.

In order to express these results in terms of water it was necessary to determine the amount of ice which would be melted by a given amount of water in cooling one degree. A vessel of sheet iron, weighing with its cover 1.7347 pounds, was filled with water, 2.74349 pounds, and placed in boiling water. The temperature attained was 79°5 R. The vessel with the hot water was transferred to the interior of the ice calorimeter, and at the end of sixteen hours it had reached the temperature of the ice. The amount of ice melted was 3.983797 pounds, of which 0.252219 pound was due to the sheet iron vessel, determined by a separate experiment. The ice melted by the hot water was, then, 3.714578 pounds. (Doubtless these figures were obtained by calculation, and do not imply extreme accuracy.)

In another experiment the warm water was poured into the calorimeter and, apparently, directly upon the ice. The amount of water used was 4 lb. 8 oz. at 70°R. There was removed from the calorimeter 9 lb. 12 oz. of water at 0°R. Hence 5 lb. 4 oz. of ice was melted by the 4 lb. 8 oz. of water. In order to have melted an equal weight of ice the temperature of the water should

have been 60°R. Another experiment gave the number 60.356. The mean of these values, "and several others" not published, was taken in round numbers to be 60°R. This is equivalent to 75°C., and this value of the heat of fusion of ice was accepted and used by physicists for the following sixty years,- from 1780 till 1840 or later.

The first determination of the heat of fusion of ice which bears the marks of accuracy is that of La Provostaye and Desains[1] in 1843. These investigators used the method of mixtures, strictly so called. That is, pieces of ice from the surface of which most of the water had been removed with tissue paper, were dropped into water and the lowering of temperature caused by the melting of the ice was measured with a thermometer. Their thermometers were graduated to tenths of a degree and read to hundredths, and were compared with standards. The amounts of water and of ice employed were determined by weighing the calorimeter first empty, then with the water, and finally after the ice was melted. The initial temperature of the water varied between 18°C. and 20°C.

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[1] La Provostaye and Desains, Ann. de Chem. et Phys. t. 8, 1843, pp. 5 - 19.

for the different experiments, being such in each case that with the amount of ice used in the experiment the final temperature would be nearly the same as that of the surroundings. By this means the radiation correction of the calorimeter was made as small as possible. The rate of cooling of the calorimeter for each degree difference in temperature between the water in the calorimeter and the surroundings was determined by a preliminary experiment. During an experiment the temperature was recorded every few seconds, and the observed final temperature was corrected for the cooling by radiation.

They estimated the amount of water clinging to the ice as about one two-thousandth of the weight of the ice, and as therefore too small to take into account in their experiments. The mean of seventeen determinations of the heat of fusion of ice gave the value 79.01 calories in terms of the mean specific heat of water over the range 10°C. to 24°C. The authors show that this value is subject to a probable error of 0.3[illegible] calorie.

The weights of the calorimeter with the water and the ice were corrected for the loss due to evaporation.

The loss of heat due to this cause if taken into account at all may have been included, consciously or unconsciously, in the determination of the rate of cooling. But in the single detailed calculation given, if an amount of water as great as assumed, and by which the weights are corrected, actually did evaporate, the cooling produced thereby would be 180 % of the total cooling correction applied !

The results obtained by La Provostaye and Desains were confirmed by the experiments of Regnault[1] made the same year. He also used the method of mixtures and pointed out the errors due to the water introduced on the ice, and to the evaporation of water from the calorimeter. No corrections were made, as these were considered too small to affect the result. This is true regarding the change in weight, as the maximum evaporation was only 0.07 gram, but the heat required to evaporate this water, if neglected, would make the computed value of the heat of fusion too great by one third of a unit.

[1] Regnault, Ann. Chem. et Phys. 1843, t.8, pp. 19 - 27.

During the winter of 1842 Regnault made several determinations of the heat of fusion of snow. The temperature of the snow was measured with a thermometer, and was always a few tenths of a degree below 0°C. When transferred to the calorimeter the snow melted very quickly, thus reducing the errors due to radiation. The specific heat of the snow was assumed to be the same as for water. The mean of four determinations gave the result 79.24 calories.

There being little snow in Paris the following winter, he used pieces of ice cut from a clear block and free from air bubbles. The ice was dried with filter paper and quickly transferred to the calorimeter, its mass being determined by weighing the calorimeter before and after the experiment. The mean of thirteen determinations was 79.06 calories, in terms of water over a mean range of from 11°C. to 22°C.

In 1848 Hess[1] conducted an elaborate series of experiments to determine the heat of fusion of ice. He avoided the errors introduced by the layer of water on melting ice by using ice several degrees below zero.

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[1] Hess, St. Petersburg Imp. Acad. Sci. Bull. de la Classe Physico-mathématique, IX, 1851, pp.31-3[illegible].

The room in which he worked was kept cool, while the balance, ice, etc., were in a glass case outside one of the northern windows. The temperature of the ice was measured by a thermometer in the midst of broken pieces in a beaker. The usual method of mixtures was used, the cold ice being placed in the water and allowed to melt. The temperatures were measured to tenths of a degree, and the amounts of ice and water so proportioned that the final temperature was that of the room. Forty determinations were made, each involving the two unknown quantities, the specific heat of ice and its heat of fusion. Solving for these quantities gave 0.533 for the specific heat of ice, and for the heat of fusion the value 80.34 calories in terms of water over the mean range of from 7°C. to 19°C.

The last investigation having as its object the determination of the heat of fusion of ice was made in 1850 by Person.[1] He criticises the values found by Regnault and La Provostaye and Desains because they had followed the methods of previous investigators and used ice at 0°C. and therefore had not taken into account

[1] Person, Ann. Chem. et Phys. 1850, t.30, p. 73.

the extra heat which, according to his notion, ice absorbs before reaching 0°C.

Person used the method of mixtures, the temperature of the water being about +18°C, and that of the ice from

-2°C. to -21°C. The ice was a cylinderical block, 4 centimeters in diamater and 12 centimeters high. This was enclosed in a sheet iron case and contained a thermometer to measure its temperature. The specific heat of the ice was determined by cooling it to -21°C. in a freezing mixture, then plunging it, case and all, into the calorimeter, which contained a saline solution a few tenths of a degree below 0°C. After ten or twenty minutes the final temperature were read. Two determinations gave 0.48 for the mean specific heat of ice from - 21°C. to -2°C.

The experiments for the determination of the heat of fusion of ice were conducted in a similar manner. The block of ice was cooled in a freezing mixture to several degrees below 0°C. and then plunged into the calorimeter, which contained water at about +18°C. Using the above value for the specific heat of ice, and

unity for the specific heat of water, he obtained the value 80.0 for what he was pleased to call the "total" heat of fusion, this being the mean of six experiments. From the recorded data it is impossible to say what the error of this result may be. The only corrections applied are for the water equivalent of the calorimeter thermometer, etc., and a correction for radiation - the determination of which is not given.

In 1870 Bunsen* devised the ice calorimeter which bears his name. As with the ice calorimeter of Laplace and Lavoisier, Bunsen used his instrument for the study of specific heats, and in order to express the specific heats of the substances studied in terms of the mean specific heat of water two auxiliary experiments were made. In these experiments he used 0.3333 gram of water enclosed in a glass tube and warmed to the temperature of boiling water. The water and tube were then dropped into the ice calorimeter, and the change in the scale reading observed. In the second experiment the same water and tube were warmed to identically the same tem-

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*Bunsen, Phil. Mag. ser.4, vol.41, 1871, p.182.

perature, and produced almost the same change in the scale reading of the ice calorimeter. Evidently the two experiments were made in quick succession without a single variation, and the two results, 80.01 and 80.04, of necessity agree very closely. The mean, 80.02, is expressed in mean calories.

The results of all these determinations are collected in Table 1. It is difficult to determine the exact temperature of the water used in these experiments but the attempt has been made to express the results in terms of joules, by making use of Barnes' values of the mechanical equivalent of heat, and the values set down in the table can not be far from right.

In all of these determinations of the heat of fusion of ice practically a single method has prevailed, that of mixtures. The limitations of this method are at once evident. No knowledge of the condition of the ice when it enters the calorimeter is possible. Unless it is melting, and has been in that condition a very long time, its temperature is entirely unknown. Experiments show that a block of ice which has been for several hours in a warm room (20°C.) may still be consid-

Table I. Summary of previous determinations.

Date	Name	Number of Experiments	Temp. Range of Water	Heat of Fusion Calories	Joules
1762	Black	2	80 - 0	79.7	
	Wilke	1	72 - 0	72	
1780	Laplace and Lavoisier	2	100 - 0	75	
1843	Provostaye and Desains	17	24 - 10	79.1	331.5
1842	Regnault	4	16 - 7	79.24	332.7
1843	Regnault	13	22 - 11	79.06	330.8
1848	Hess	40	19 - 7	80.34	337.1
1850	Person	6	16 - 5	80.0	335.9
1870	Bunsen	2	100 - 0	80.02	335.2

erably below 0°C. in the interior. If such a block is broken up and soon used, even the small pieces will be colder than 0°C., altho melting on the exterior. Again when the ice has been melting long enough to insure its temperature being very close to 0°C. it is impossible to remove all of the water from the ice, and an unknown amount of water is thus carried into the calorimeter and credited up as ice. It is not necessary that this water should be solely that of the superficial layer covering the ice. Unless the ice has been formed from exceedingly pure water, and is uniform throughout, melting will occur at interior places, the resulting water remaining in its own cavity. The amount of water which may thus exist throughout the ice is neither determined nor removed, but is counted as so much ice.

Moreover, this method involves the measurement of changes in temperature, which at best involves considerable uncertainty, especially when mercury thermometers are used; and as the results are expressed in indefinite units, the whole subject has been left in a most unsatisfactory condition.

GENERAL METHOD.

The method employed in the experiments now to be described may be briefly stated as follows. The sample of ice, whose heat of fusion is to be determined, is broken into small pieces and cooled several degrees below 0° C. While at this temperature it is weighed and transferred to the calorimeter, which contains kerosene oil also two or three degrees below 0° C. In this state there can be no question that the ice is entirely free from water, either on the outside or interior. The calorimeter and contents are slowly warmed by a very small electric current until the temperature reaches the desired point for commencing an experiment, usually about - 1° C. A larger current is then applied for sufficient time to melt the ice and raise the resulting water to about +0°.5 C. At this temperature (of equilibrium) the ice has certainly all been melted, and the heat generated by the current has been used in four ways: 1st, in raising the temperature of the ice and the calorimeter from about -1° C.

to 0° C. 2nd. in melting the ice. 3rd. in raising the temperature of the water and calorimeter from 0° C. to about +0.5 C., and 4th. in supplying whatever heat is lost by the combined effects of radiation, conduction, convection, etc. Of these four quantities of heat, the second is thirty or forty times as great as all the others combined, which are determined as corrections, and when subtracted from the total amount of heat generated by the current, gives the heat required to melt the ice. This amount of heat divided by the mass of the ice gives the heat of fusion per gram of ice.

In order to provide a medium for the transference of heat from the wire carrying the current to the ice, and to enable the different parts of the calorimeter to attain an equilibrium temperature, a bath of refined kerosene known as "Pratt's astral oil" was used. This oil could be cooled to any desired temperature without losing its fluidity, and it had no action on the ice,- two points which are only possessed by this fluid, as far as could be learned.

The amount of heat produced in the heating coil by the current was determined by measuring the differ-

ence of potential between the terminals of the coil, the current which flowed through it, and the time during which the current was flowing. The heat, in joules, is then given by the formula, EIt.

Each experiment is naturally divided into three parts - 1st, the determination of the heat capacity of the calorimeter, ice, oil, etc. 2nd, the melting of the ice, and 3rd, the determination of the heat capacity of the calorimeter, water, oil, etc. These are discussed in order below.

Heat Capacity of the Calorimeter, Ice, etc.

The amount of heat required to raise the ice, oil, calorimeter, etc. from the initial temperature to 0° C. was determined from the rate of warming during the preliminary heating. The current used for this was one tenth as large as that employed in melting the ice, thus generating one hundredth as much heat per minute. This small amount was used in order to warm the ice slowly and without melting any of it. As 0° C. is approached it was more and more difficult to apply heat and not allow any portion of the oil, even close to the wire,

to become warmer than 0° C. With care there was never any trouble from this source when the temperature was as low as - 1° C.

The heat capacity of the entire apparatus, including the ice, was found as follows. The temperature was read every minute, while the ice and oil were constantly stirred, until the rate of warming due to the combined effects of radiation, conduction, convection, stirring, etc., was nearly constant for ten or fifteen minutes. Then the small current was passed for ten minutes, the stirring being continued at the same rate, while the temperature rose more rapidly. Following this another series of temperature readings was taken while the calorimeter continued to warm up by heat from without. The rate at which the calorimeter was receiving heat from without while the current was flowing, by Newton's law, which is shown below to apply to this case, is the mean of the rates just before and just after (since the temperature, on the average, is a mean between the temperatures before and after). The total amount of heat received by the calorimeter and its contents causes a certain rise of the thermometer, and since the tempera-

ture at the begining and the end is changing very slowly it is safe to assume that the thermometer indicates the temperature of each part of the calorimeter, including the small pieces of ice. The difference between this observed change in temperature and that which would have been produced during the same time by outside influences alone, gives the change in temperature due to the current. This establishes the relation between heat (expressed in joules) and the change in temperature produced by the addition of this amount of heat. On the assumption that the same amount of heat will produce the same temperature change at any temperature up to 0 C., it is a simple matter of proportion to find the number of joules required to raise the calorimeter and contents from the initial temperature to 0°C. That this assumption is fully warranted is shown by experiments given below.

Melting the Ice.

The first part of the experiment is followed directly by the second, which differs from it only in the quantity of heat employed and the consequently

greater changes in temperature, together with the melting of the ice. The current is about two amperes and flows for twenty or thirty minutes, while the stirring continues uninterrupted at the same rate as before. Two observers are required during this portion of the experiment,- one to continue the stirring and read the thermometer and keep the records, while the other attends to the regulation and measurement of the electrical energy.

In series with the heating coil was placed a standard half ohm coil which was specially designed for carrying currents as great as two amperes. The current through these coils was maintained constant at about two amperes by regulating it so that the fall of potential in the standard coil always just balanced the E. M. F. of one standard Weston cell. Each minute, or as often as possible, the difference of potential between the terminals of the heating coil was measured with a potentiometer and standard cell. The time during which the current was flowing was measured with an Elgin watch with the aid of a reading glass. This measurement of both the current and the difference of

potential makes the experiment more complicated and laborious than it would have been to simply maintain a constant current through the coil and calculate the heat from the formula RI^2t, where R denotes the resistance of the heating coil; or to maintain a constant E. M. F. and calculate the heat from the expression $\frac{E^2t}{R}$. In each of these cases a knowledge of the resistance R, would be required, and this mean a knowledge of the temperature of the wire when carrying the current, which may be several degrees warmer than the surrounding bath and in any case is very dificult to determine. All of this uncertainty regarding the resistance of the heating coil is avoided by the method here adopted, and the increased labor is more than repaid in the increased confidence in the measurement of the electrical energy.

Heat Capacity of the Calorimeter, Water, etc.

After the ice is melted and the current stopped, the water, oil and calorimeter come to some equilibrium temperature a few tenths of a degree above 0°C. The amount of heat which has been expended in raising the temperature above 0°C. is found by another experiment

in all respects similar to that performed below 0° C., and just described. The heat capacity will, of course, be greater than before, since the calorimeter now contains water instead of ice. It has been shown by Barnes that the specific heat of water exhibits no peculiarity in the neighborhood of 0° C., and therefore within the limits of accuracy here required, the heat capacity of the entire apparatus is the same at about +1°.8 C. that it is over the range from 0 C. to +1°.5 C.

Correction for Radiation, Conduction, Convection and Stirring.

There remains another important correction, viz., the heat lost to the calorimeter by radiation, conduction, convection, stirring, etc. during the period in which the ice is being melted. This is determined in much the same way as in the auxiliary experiments just described. The bulb of the thermometer is near the wall of the calorimeter and it is assumed that the temperature of one represents the temperature of the other. Newton's law of cooling is assumed, that is, that the heat lost each minute is proportional to the

difference in temperature between the wall of the calorimeter and the surroundings. From the data already obtained the rate of cooling (or warming) at several temperatures both above and below 0° C. is given. These rates of cooling are expressed in terms of the equivalent joules per minute and plotted as ordinates against the corresponding temperatures as abscissae. The curve joining all these points is very nearly a straight line, and if Newton's law is true it should be absolutely a straight line. Therefore the straight line which lies nearest to the plotted points is drawn, and this line then gives the heat lost per minute at any temperature.

The heat lost by the calorimeter through the combined effects of radiation, conduction, convection, stirring, etc., during the interval in which the ice is melting is then obtained from this curve as follows. As the temperature is measured each minute, the average of these readings gives the mean temperature during the experiment. The ordinate on the curve corresponding to this temperature gives the mean loss of heat per minute. This quantity multiplied by the time in minutes gives the total loss of heat radiation, etc.

DESCRIPTION OF APPARATUS.

In devising a form of apparatus suitable for the accurate determination of the heat of fusion of ice, two things were especially desired. First, that it would admit using different samples of ice, and ice formed under different circumstances, and secondly, that it should have as small a radiation constant as possible. The first condition debarred the Bunsen calorimeter, or any similar instrument, even if it had not been shown that the density of ice depended upon the method of manufacture, and therefore rendered this instrument incapable of accurate results.

After a number of preliminary experiments upon the radiation constants of different calorimeters (i.e. the heat lost or gained per minute per degree difference of temperature between the calorimeter and its surroundings) it was found that the best protection against radiation was the double wall of a Dewar bulb. Accordingly a half liter Dewar bulb was used for the basis of the calorimeter. This was supported within the chamber D, Fig. 2,

by a special wooden clamp which fitted around the neck of the bulb. The upper portion of this clamp passed upwards through the tube T, which it completely filled and by which it was supported. The thermometer, stirrer rod, and current leads passed through appropriate holes, drilled lengthwise in this clamp support.

This form of calorimeter proved very satisfactory and fulfilled the highest expectations regarding the loss or gain of heat by conduction and radiation. When filled with water a few degrees below the surroundings it warmed up at the rate of 0°.0016 C per minute per 1° C. difference in temperature between the interior and the exterior.

A preliminary experiment to see how rapidly ice could be melted without unduly raising the temperature, was performed as follows. Since only qualitive results were desired the bulb was filled with water instead of kerosene, and a few hundred grams of broken ice dropped in. On supplying heat by a current through the coil, the gratifying result was obtained that 50 watts raised

the temperature to only +0°.5 C. In other words, ten grams of ice could be melted per minute without raising the temperature over 0.5 C. and consequently without producing much loss of heat by radiation.

But this fair begining was doomed to speedy disappointment. In the midst of the next experiment, the inner wall of the bulb expolded with a loud report, the contents and broken glass being caught and held by the outer wall, which did not break. No possible reason could be fould why the bulb should have given away at just that time. Fortunately the thermometer, which was witin the bulb, escaped uninjured. Several weeks were spent in trying to obtain a duplicate bulb. The first one obtained had a much smaller neck, and while superior to the original in some respects it could not be used on the same supports, and did not give sufficient space for the thermometer, stirrer, current and potential leads, etc. After much correspondence, a bulb was obtained very like the original, and the experiments were resumed.

On trying the complete experiment and using kerosene as the fluid, the ice, as expected, sank to the bottom of the bulb. When the current was passed to melt the ice, the temperature was found to be much higher than it was in the preliminary experiments in which the ice floated at the top of the warmed fluid (water). This was doubtless due to the warmer oil rising to the top and away from the ice, which remained in a more or less compact mass at the bottom and presenting a minimum of surface to the action of the oil.

Many ineffectual attempts were made to support the ice in the oil with the heating coil below it. Various kinds of stirrers were tried in hopes of securing a more thorough circulation of the oil amongst the pieces of ice, but with limited success. The principal difficulty was in the smallness of any arrangement which could be passed through the neck of the flask. Finally, almost by accident, a form of rotary stirrer was found which secured complete circulation and promised satisfactory results. But disappointment was again in store. One day as the bulb containing some oil was resting upon the

bed of excelsior where it was kept when not in use, a loud report was heard, and that bulb was no more! The destruction was complete, some of the pieces being thrown a distance of a meter away. I was only thankful it did not occur when in use, with the delicate thermometer inside.

Of course another bulb could have been obtained, but the danger of its exploding at any moment, and especially the risk of destroying the thermometer, was so great, it was decided to use some more stable form of apparatus. Moreover it was now the first of January with cold weather approaching, during which all the experiments would have to be performed. The shortness of time forbade much waiting for the construction of elaborate apparatus, and therefore the best that lay at hand was tried. While not equal to the Dewar bulb in preventing loss of heat by radiation, still it was very good, and the certainty of its remaining intact fully balanced any inferiority in other respects.

Final Form of Calorimeter.

The calorimeter as finally used is shown in section in Fig. 1, which is nearly self explanatory. A is a half liter brass vessel, nickel plated and highly polished on the outside. Within this is shown the stirrer and the heating coil. cc is a brass tube over which is wound five ohms of No. 22, silk covered, manganin wire. The wire is insulated from the tube by a double thickness of silk, and the whole covered with several coats of shellac well baked on. The ends of the coil are soldered to two heavy copper leads, aa, to the upper ends of which are soldered the current and potential leads. The stirring is effected by a disk of brass, dd, which nearly fits the calorimeter, and is soldered to the lower end of the brass tube, cc. It is perforated by a number of small holes through which some of the oil can circulate while the greater part of it streams through the heating tube as the stirrer is moved up and down. The stirrer rod, rr, is a hard rubber tube which screws onto the end of one of the heavy copper leads. It extended upward to the outside alongside the thermometer, and also served to support

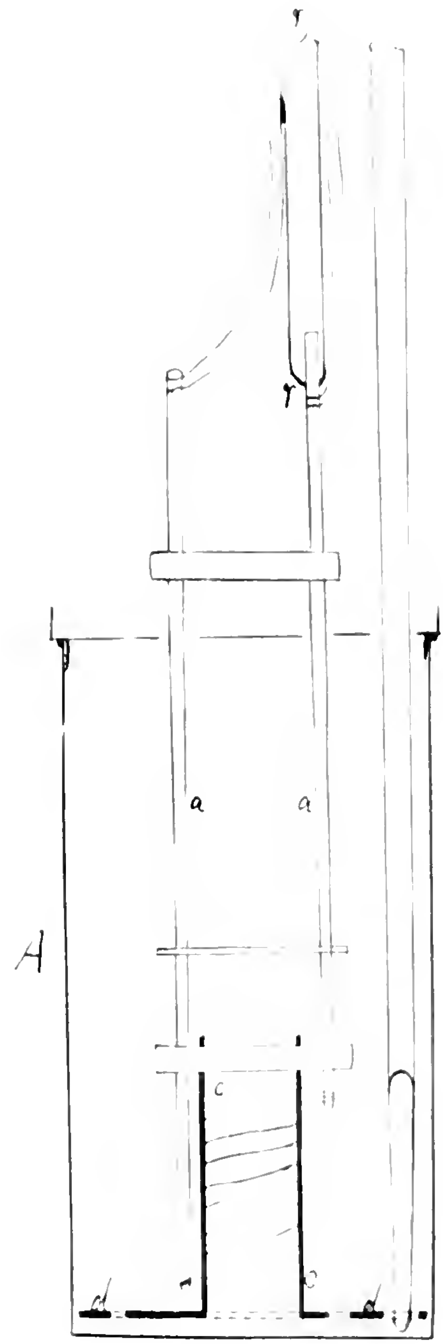

Fig. 1.

the current and potential wires.

On one or two occasions during the preliminary experiments a few drops of oil were found to have spilled out of the calorimeter, which of course would seriously affect the weight of the apparatus at the end of an experiment, to say nothing of the change in the heat capacity. To prevent this as far as possible a tightly fitting cover was made. Openings were necessary for the thermometer, the stirrer rods, and for the tube through which the ice was dropped. A lid was arranged to fall and cover the latter opening when the tube was withdrawn. An edge was placed around the cover to hold whatever oil might find its way to the top. This precaution may have been unnecessary, as no oil was ever found on the cover.

The calorimeter was supported in the following manner. Sufficient cotton wool was wrapped around it to just slip into a large glass battery jar. This jar rested upon a wooden block at the bottom of the chamber D, and to prevent as far as possible the loss of heat

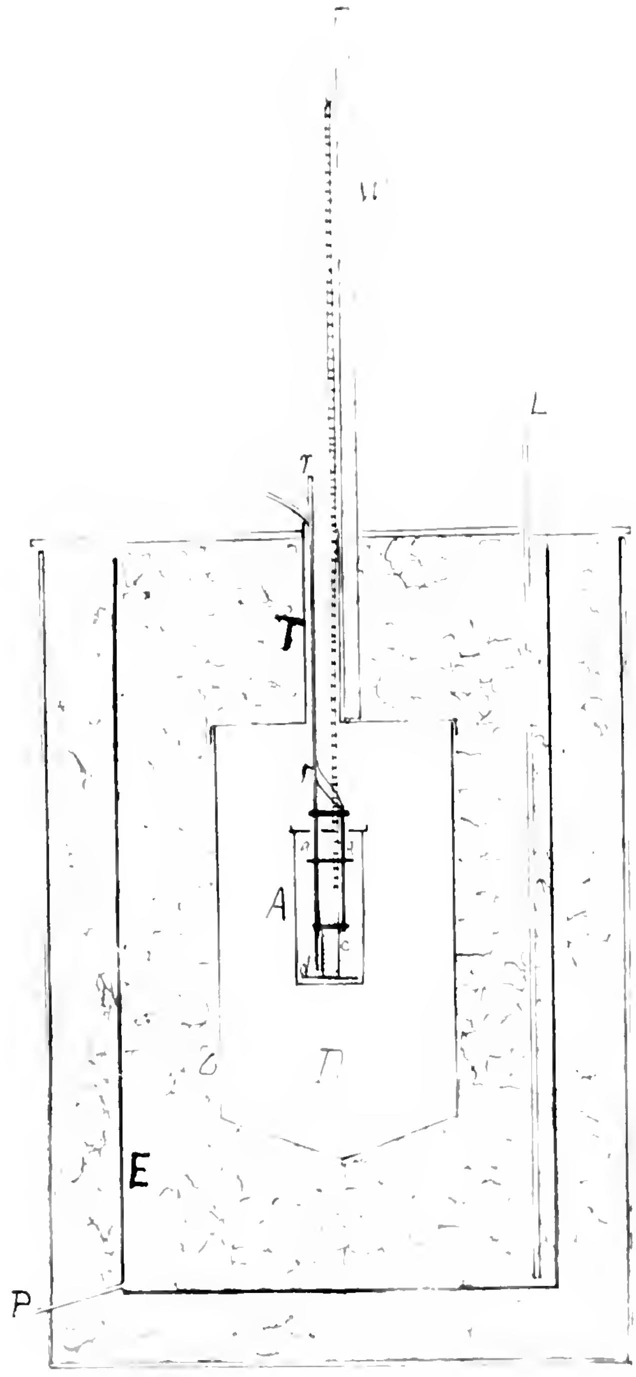

Fig. 2.

by convection air currents the remaining space was filled with cotton wool.

The dimensions of this chamber are 35 cms. in depth, by 23 cms. diameter, it being circular in section. The larger vessel, E, is 70 cms. deep and 45 cms. in diameter, it also being circular in section. Both of these vessels were made of heavy galvanized iron. The space between them was filled with broken ice, making a layer 11 cms. in thickness around the sides of the inner chamber, and about twice this thickness over the top and bottom, thus maintaining the temperature of the interior chamber very closely to 0° C. The top of this chamber is a removable cover, made with an outside flange to prevent water from gaining access to the inside. At the center of this cover is a tube 4 cms. in diameter and 20 cms. in length, which extended through the broken ice to the outside, and through which passed the thermometer, stirrer rod, current wires, etc. In order to protect this broken ice as much as possible from outside heat, the vessel E was placed within an extra large barrel with the intervening space packed

with excelsior. With this protection the amount of ice melted was about ten kilos per day, this amount being added each morning. The total quantity of ice required for this packing around the chamber was about sixty kilos. As fast as it melted the water was drained away through the tube P. Over the barrel was a wooden cover through which projected the tube T, the wooden post, W, which served as a support for the thermometer when in use, and the thermometer case, L, in which the thermometer was kept during the time between experiments.

In order to fill the calorimeter with oil and ice a thin brass tube was arranged parallel to the thermometer and extending from the outside to about half a centimeter below the cover of the calorimeter. Within this tube was a glass funnel through which the cold oil was poured. The funnel was then removed and the ice dropped through the tube, after which the tube was removed, the small trap door falling and closing the opening in the cover. The tube T, was then filled with cotton to prevent circulation of the air between the inner chamber and the outside, it being firmly packed

around the thermometer and stirrer rod, but allowing the necessary motion of the latter.

Electrical Arrangements.

A diagram of the electrical connections is shown in Fig. 8. C is the heating coil within the calorimeter M is the standard half ohm coil, while D is an auxiliary coil of resistance equal to to C andM together. The current was obtained from eight storage calles, B, and by means of the switch S, could be passed through the auxiliary coil D while it was adjusted to approximately the proper value by the variable resistance, R. The latter consisted of a rheostat containing a total of six ohms of heavy iron wire, in parallel with which was a liquid resistance of copper sulphate solution. By this means as small variations in the current as desired could easily be made. When ready to use the current in the calorimeter, the double pole, double throw switch S, was closed on the other side, and the current quickly brought to the proper value by a very slight adjustment of the resistance R.

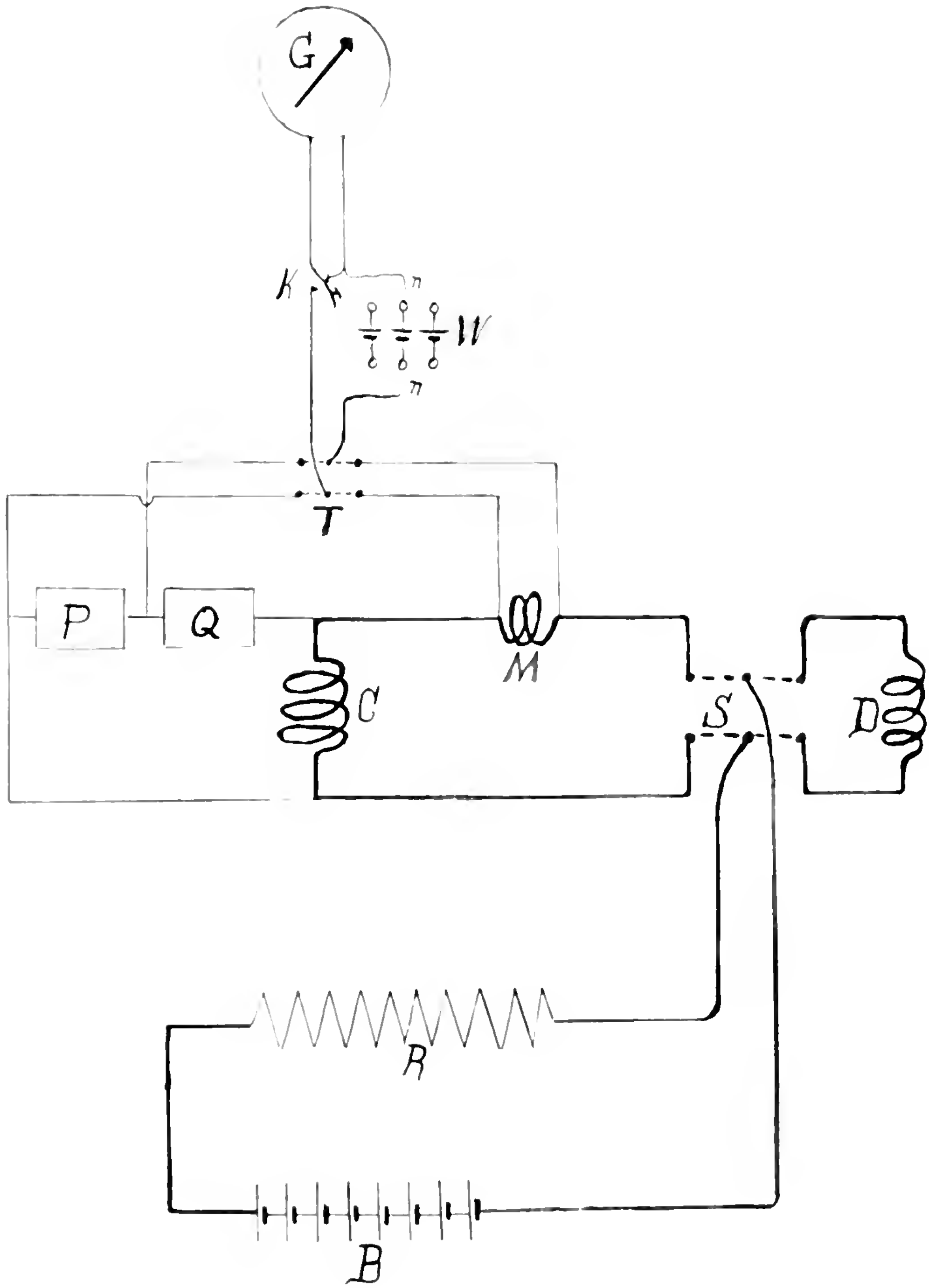

FIG. 3.

The galvanometer, G, was the Rowland D'Arsonval wall type and quite sensitive. Its free period of vibration was about 15 seconds, with little damping and requiring several minutes to come to rest after a deflection. In this work it is necessary to take readings almost continuously, which requires a dead beat instrument, and the galvanometer was modified in the following manner. A large mica vane was fastened to the back of the mirror; a copper tube was fitted over the coil so as to turn with it through the magnetic field between the poles of the permanent magnet; and the coil of the galvanometer was shortcircuited by the key K when open. These three methods of damping rendered the galvanometer sufficiently dead beat to be used, if care was taken never to allow deflections of more than 20 mm. Usually however the deflections were about 1 or 2 mm.

Three Weston standard cells, W, were used for the measurement of the current and E. M. F. They were connected to three pairs of mercury cups, as shown, and any one of them could be inserted in one of the galvanometer leads by placing the wires, nn, into the corres-

ponding mercury cups. The ends of these wires were fastened in a block of hard rubber and projected about a centimeter beneath. By simply lifting this block from one pair of cups to another any one of the standard cells could be brought into use. One cell was used throughout one experiment (about half an hour) during which interval its constancy was several times tested by substituting an unused cell in its place for a single reading. No sign was ever found that the cells suffered the least change in their E. M. F. when in use. These cells were certified to have a constant E. M. F. at all temperatures between 10 C. and 35 C. but they were always used at very nearly 20 C.

The absolute value of the E. M. F. of these cells was determined by the National Bureau of Standards, where one of these cells (No. 329) was compared with ten standard Clark cells. Assuming the Clark to be 1.434 volts at 15° C the E. M. F. of this cell was found to be 1.0193 volts ...

The results of all the experiments, save two, are expressed in terms of this cell. In the other two,

the standard cell No. 298 was used, the E. M. F. of which was less than the other by 1 part in 10000, as shown by the maker's certificates, and also by a direct comparison at the time they were used. Hence the E. M. F. of this cell is taken as 1.0192 volts.

The standard half ohm coil, M, is of the Reichsanstalt form as made by Leeds & Co., and was made with special reference to carrying currents as great as two amperes. It is provided with both current and potential terminals, the half ohm being the resistance between the two points where the potential terminals are attached. The exact value of this resistance was determined by the National Bureau of Standards, and was found to be 0.50003 ohm in terms of the mean values of two coils which were redetermined at the Reichsanstalt in July 1902. Copies of these certificates are appended at the end of this dissertation.

As shown in the figure, the current terminals are joined in series with the heating coil, and the

potential terminals are joined to one side of the double pole, double throw switch, T. When this switch is closed the difference of potential between the terminals of the standard half ohm is balanced against the E. M. F. of whichever standard cell is in circuit, the difference, if any, being indicated by the galvanometer on closing the key K. The main current through C and M is continually adjusted to keep the galvanometer deflection zero. The observer sits with his eye at the telescope watching the galvanometer deflections, while one hand continually tapped the key K, and the other varied the resistance R whatever was necessary to maintain zero deflection.

In order to be protected as far as possible from fluctuations in temperature, the standard cells and resistance were placed in a wooden box and covered with cotton wool. This box occupied a position on the table, found by trial, such that that the heat from the register and the cold from the window balanced to give a nearly constant temperature of about 20°C. Quite large fluctuations in the temperature of the room, if not continued too long, produced very little change within the box.

Measurement of Current.

As explained above, the current through the heating coil was maintained constant by keeping the galvanometer deflection as near zero as possible. The deflections to one side or the other were usually less than one or two millimeters, and the corresponding steady deflections could they have been observed, would have been considerably less. As the deflections were as often one way as the other, the too small current at one time would tend to balance the too large current of another, thus making the actual average current through the calorimeter differ less from its intended value than if the deflections were all in the same directions. The sensitiveness of the entire arrangement was such that a steady deflection of one millimeter corresponded to a variation in the current of about 1 part in 10,000.

Knowing the resistance of the standard coil, M, and the difference of potential between its terminals, the current it carries is readily calculated by Ohm's law. The current in the heating coil, C, is equal to that in M, less the small portion which flows through the potentiometer circuit, PQ.

Measurement of E. M. F.

The difference of potential between the terminals of the heating coil was measured by the usual potentiometer method as shown in Fig. 3. **Q** is a fixed resistance of 10,000 ohms, while **P** is about 1100 ohms. Both resistances in series are joined in parallel with the heating coil and thus are subjected to a total fall of potential of about ten volts, of which a little over one volt is in the part **P**. As shown in the diagram, two lead wires from the terminals of **P** run to the switch **T**. On throwing the switch to this side, the fall of potential in **P** is compared against the E. M. F. of the same standard cell used for the measurement of current. The resistance of **P** is varied to give zero deflection of the galvanometer. Then if **E** is the E. M. F. of the standard cell and **P** is the resistance corresponding to zero deflection of the galvanometer, the difference of potential, **V**, measured by the potentiometer is given by the expression,

$$V = \frac{Q + P}{P}$$

When running an experiment, the switch, **T**, was

kept closed on the current side in order to see that the latter remained constant. When everything was going smoothly the switch was quickly thrown to the other side - the direction of the galvanometer deflection noted - and then thrown back again. The smallest change in P corresponded to a deflection of eight scale divisions, and when it was not possible to adjust P to give zero deflection, the small deflection was observed and the value of P corrected accordingly.

The temperature of the potentiometer coils, or at least that outside of the boxes which contained them, was about 20°C. in all of the experiments here reported. As it is the ratio of the resistances of these coils that is used in the measurement of E. M. F. any small change in temperature would affect this ratio very much less than it would the absolute value of the resistances. In fact it would be proportional to the difference between the temperature coefficients of the two portions of the total resistance, and is therefore inappreciable for a variation of one or two degrees, or even more.

Measurement of Time.

Time was measured by an Elgin watch which was losing less than thirty seconds a month. The seconds hand was viewed with a small reading glass which magnified five diameters, and just as the 30-seconds mark was covered by the hand, the switch S was closed, thus starting the current through the coil C at the begining of the 31st second. When it was desired to stop the current the same procedure was repeated. Whenever the length of time was arbitrary and would allow it, the current was allowed to flow an integral number of minutes, so that the seconds hand of the watch could be read in the same position at both the starting and the stopping of the current.

In order to obtain some idea of the accuracy with which intervals of time could be measured by this method, twelve single minute intervals as observed with the watch were recorded upon a chronograph sheet which was also receiving the records of seconds from the astronomical clock.

The duration of these intervals as obtained from the chronograph are given below.

60.22	60.15	60.15
60.23	60.22	60.25
60.15	60.15	60.10
60.20	60.15	60.15

Mean of all = 60.177. Prob. error = 0.010

(60 solar seconds = 60.165 sideral seconds)

The probable error of one observation is 0.03 sec. and the greatest difference of a single observation from the mean is 0.08 second. From this it appears that intervals of time measured with the watch can be depended upon to at least a tenth of a second, and they probably possess a greater accuracy.

<u>The Thermometer.</u>

The thermometer used in these experiments was one made to order by H. J. Green of Brooklyn, N. Y. It was graduated on the stem to hundredths of degrees from - 12°C. to + 1°.8 C. Its entire length was 95 cm. and it was 6 mm. in diameter. The bulb was long (3 cm.) and thin, thus quickly taking the temperature of the

bath in which it was placed. The stem from - 5°C. up was above the top of the barrel, and with the aid of a small reading glass the temperature could easily be read to thousandths of a degree.

The zero of this thermometer was too low by 0°.035, that is, the temperature of melting ice gave the reading + 0°.035 C. This difference is doubtless due in part to the fact that the stem was exposed to the temperature of the room (about 20° C.), but as this was the same in the actual experiments and when the "zero point" was determined no error is introduced by not applying the stem correction. The "zero point" was determined before and during the experiments by three different methods, viz., by placing the bulb and several centimeters of the stem into a mixture of clear ice and pure distilled water; by plunging it into freshly fallen snow which was saturated with pure distilled water; and by placing it in pure distilled water which was being frozen in a large test tube. Each of these methods gave the reading + 0°.035 C. as the true zero, and all readings of the thermometer are corrected by this amount.

The brass case of the thermometer was kept standing in the ice surrounding the chamber D, and when not in use the thermometer was always within this case and at a temperature not higher than two or three tenths of a degree above zero. During the entire series of experiments here reported the thermometer was not allowed to rise above + 2° C. and the lowest temperatures to which it was subjected rarely exceeded - 5° C.

Manipulation of the Ice.

The ice used in these experiments was very carefully selected, only that which was perfectly clear and transparent and free from bubles being taken. The structure of all the ice used, both the commercial ice and that made from pure distilled water, was decidedly crystalline the axis of the crystals being normal to the surface at which the ice was formed. A piece of ice which externally appeared the same in all directions, quickly revealed its crystalline nature when the attempt was made to split it. If the edge of a sharp knife was pressed against the ice to divide it along the axis of

crystallization, it readily separated along an almost perfect plane. The same is true of the planes at right angles to the axis, provided it is not too near the end of the crystals. In any other direction, and even that perpendicular to the axis if too near the end of the crystals, the pressure of the knife resulted in merely shattering the ice as tho it were a bundle of glass tubes. By cleaving the ice in planes at right angles and parallel to the axis of crystallization it is possible, however, to divided it into small cubes with smooth surfaces, each one of which was as clear as the original piece.

As the weather was seldom cold enough to keep the ice from melting, about 100 grams of these pieces were dropped into a beaker surrounded by a freezing mixture. To prevent their freezing to the sides of the beaker a few pieces were introduced at a time and constantly stirred until they were cooled below 0° C, and whatever free water there might have been on the surface was completely frozen. The beaker was then closed with a ball of cotton wool to prevent the warmer air from

coming in contact with the ice, and left in the freezing mixture some minutes longer.

In the meanwhile the proper amount of oil was measured out into a flask, weighed, and placed in a freezing mixture, where it was cooled to about - 6° C. This flask was now removed, and the oil quickly poured into the calorimeter through the special funnel. Both the flask and the funnel were then laid aside to assume the temperature of the room, when they were reweighed to determine just how much oil entered the calorimeter.

In order to weigh the ice without its melting, the beaker containing it is removed from the freezing mixture, quickly wiped dry, wrapped with cotton, and placed within a larger beaker, the whole being covered with a paper maché cap. This arrangement was placed on the balance and weighed. It is then carried to the calorimeter, the cover and ball of cotton removed, and the ice poured through the brass tube into the cold oil below. The ice is directed into this tube by a funnel formed of filter paper. At no time was the appearance of the ice such as to indicate that any portion was melting.

nor was any water ever caught by the filter paper as the ice passed over it. The fall of the ice was broken by the ledge, D, of the stirrer and thus splashing of the oil is prevented. Usually the ice was in the oil of the calorimeter within three minutes after it was taken from the freezing mixture, and thus the opportunity for any melting of the ice, or of any change in weight due to evaporation, was very slight indeed. After pouring the ice into the calorimeter the beaker was closed with the cotton ball, the cover replaced, and the whole immediately weighed thus determining the amount of ice employed.

If the equilibrium temperature of the oil, ice and calorimeter was much below - 2°C or - 2°.5 C. it was cautiously raised to this point, and then left for about an hour during which time it slowly rose some tenths of a degree further. At this point readings of temperature were commenced, while the oil and ice were constantly stirred at a uniform rate. By alternating periods of warming due to radiation alone with periods in which the rate of warming is increased

by an electric current through the coil, the relation between change of temperature and joules is obtained as already explained.

When the temperature reaches - 1° C., or thereabouts the larger current is applied for a sufficient time (as determined by previous calculation) to melt the ice. During this time one observer constantly w atches the galvanometer and maintains the current constant, while the other continues the stirring and reads the thermometer each minute. These readings are utilized in the calculation of the heat lost by radiation during the experiment.

After the experiment is concluded the calorimeter with the oil and water is again weighed to furnish a check upon the weight of ice used. This weight was always within a few centigrams of the sum of the weights of the separate portions.

SOURCES OF ERROR.

The various sources of error in this method are:

1. Heat lost by radiation, conduction, convection, etc.
2. Heat produced by stirring.
3. Electrolysis of the water.
4. Loss of heat by evaporation.
5. Use of the thermometer.

Under the first head it must be noticed that the temperature of the calorimeter was always within two degrees of 0°C., while the temperature of the surrounding walls of the chamber were very close to 0° C. It is assumed, according to Newton's law, that the heat lost by radiation is directly proportional to the difference between the temperature of the calorimeter and that of the surrounding walls. To prove that the loss of heat did thus depend upon the temperature of the calorimeter at the time, and not upon previous temperatures, two determinations of the heat lost at a given temperature were made. In one this temperature was reached by

adding some very cold oil, after which the rate of cooling was observed for a considerable time. Again this temperature was reached by quickly warming the oil several degrees by the electric current. The rate of cooling, after the first few minutes, was identical with the former, thus showing that it depended solely upon the temperature at the moment.

The loss of heat by convection air currents is reduced to a minimum by filling the space around the calorimeter with cotton wool.

Whatever heat may be conducted to the calorimeter from the outside by the wires conveying the current is included in the determination of the heat lost by radiation, etc. However this is very small since these four wires are of No. 16 copper wire, and the heat would have to be conducted a distance of 30 cms. and through air at 0°C. The heat generated in these wires by the current is about one joule during each experiment and is therefore inappreciable.

It thus appears that the loss or gain of heat due to these causes is a definite quantity capable of being

determined. As this determination is based upon measurements made just before and just after the main experiment, the total error introduced cannot exceed a few joules.

Heat produced by stirring.

By extremely vigorous stirring it was possible to produce enough heat to cause an observable effect upon the rate of cooling due to radiation, etc. As ordinarily used, however, the stirrer was raised and lowered about three centimeters fifty or sixty times a minute. At this rate no different effect could be obsrved from that when the stirring was only four times per minute. The heating must therefore be very small, and whatever it is it is taken account of in the correction which is determined for radiation, etc.

Electrolysis of the water.

This is impossible at the commencement of an experiment as there is no water present. It can hardly be present later as the coil is well coated with shellac, wetted with kerosene oil, and only a small portion of one end is ever below the surface of the water.

Loss of heat by evaporation.

In the usual method of mixtures there is always a considerable amount of evaporation from the surface of the water, and a consequent loss of heat. In these experiments, however, the water is covered by the oil and there is no evaporation. The oil itself evaporates exceedingly slowly, and whatever heat is thus used is included in the determination of the loss by radiation, etc.

Use of the thermometer.

The thermometer was used to measure the initial and final temperatures for determining the amounts of the corrections to be applied. As this is a very good standard thermometer recently made by Green, it is very improbable that there is any appreciable error in the length of that portion of the scale here used. The greatest error is introduced in the assumption that the temperature indicated by the thermometer truly represents the temperature of all portions of the calorimeter. As these readings were taken only when the temperature was changing very slowly and while the contents of the cal-

orimeter were thoroughly stirred, this assumption can not be very far from the truth.

WEIGHTING OF THE EXPERIMENTS.

Each of the eight experiments here reported was conducted with the greatest care, and there is no reason for discrediting the result of any one of them. Nevertheless there are certain circumstances to be noted which warrant greater confidence in some experiments than in others, and these considerations are taken into account by the following system of weighting.

The maximum weight given to any experiment is 6, made up as follows:-

One point if there has been a direct determination of heat capacity with ice preceding the regular experiment of melting the ice.

One point if the regular experiment has been followed by a direct determination of heat capacity with water.

Two points for a short duration of the experiment, that is, less than forty minutes.

One point if all the ice is melted with a single application of the current.

One point if the rate of cooling at the end of the experiment is definite and constant.

PRELIMINARY EXPERIMENTS.

The first experiments were made using the clearest portions of the artificial ice furnished to the laboratory. It was intended to use this ice for the preliminary work and later to try some ice frozen from the purest water obtainable. It was expected from the statements of some of the earlier investigators along this line, especially the paper by Person, that the specific heat of ice would increase gradually with increase of temperature from its value at - 2°C. and lower temperatures, and possibly approach the value for water as 0°C. was reached. In determining the heat capacity of the combined apparatus with ice for temperatures approaching 0°C. this idea seemed to be corroborated by experiment. A great many experiments were

made to determine the exact value of this increased heat capacity. At first all determinations were for temperatures below - 0°.5 C. and the increased heat capacity of the ice did not exceed that of water. Later, when the range from - 0°.5 C. to 0° C. was studied the heat capacity came out as being inversely proportional to the temperature below 0 C., increasing without limit as 0° C. was approached ! This at once raised suspicions that something was wrong, and further investigation showed that there had been some melting of the ice. When the temperature of the oil and ice was already very near to 0° C. it is probable that the current, tho very small, raised the temperature of some portions of the oil to such a temperature that local melting of the ice was possible. Whatever water was detached from the ice and remained in the oil in small drops, would not freeze again when the equilibrium temperature was reached. However it was never possible to find sufficient water to account for <u>all</u> of the heat absorbed, and doubtless the remainder was used in internal melting. As shown below, unless the ice is abso-

lutely pure throughout, those portions containing the greatest amount of impurities will melt first and at the lowest temperatures. As the temperature is raised a greater and greater amount of the impure ice will reach its melting point, requiring an ever increasing amount of heat to produce a given change in temperature. The water from this melting could remain on the surface of the ice, or if the melting was internal it would remain in its own cavity. Altho in contact with the ice this water (or rather solution) could not be expected to freeze again and return its heat of fusion to the oil, even tho the equilibrium temperature was two or three tenths of a degree below 0°C.

Moreover, at this time the entire question was complicated by the possibility that the oil might have some action upon the ice. This hardly seemed probable from the nature of the substances, and the fact that other investigators have observed no action upon ice when placed in refined kerosene. It is proved below that there is no such action.

Specific heat of ice.

There was now an imperative demand that the specific heat of ice be carefully studied over the range of temperature from - 1° C. to 0° C. Ordinary distilled water was placed in a large test tube with a smaller test tube suspended in the center. The water was frozen from the bottom up, thus forming a cylinder of ice between the two test tubes, about seven millimeters in thickness and as many centimeters in height. A new heating coil was arranged at the bottom of the calorimeter and occupying only about one centimeter in depth. Over this was placed the test tube containing the ice. Any possible action of the oil upon the ice was now entirely eliminated as they were separated by the glass wall of the test tube. Heat was slowly applied by the small current through the coil, and the heat capacity of the ice determined as before. Altho much less than before, yet at - 0°.2 C. it appeared as great as for water and at - 0°.1 C. it was twice as great. On removing the tube and closely examining it, a bit of water was seen at the point where the last ice was formed. Doubt-

less this drop contained the greater part of whatever impurities existed in the tube of water, and being the last to freeze it was the first to melt.

After this only the purest water was used for making ice. Such water was obtained from Dr. Jones who kindly furnished all that was needed. This water was prepared by distilling ordinary distilled water from a solution of chromate acid, the vapor being then passed directly into a boiling solution of barium hydroxide to remove all traces of carbonic acid. The vapor was then condensed in a block tin condenser and collected in a glass bottle. The latter was previously treated with boiling hydrochloric acid for a long time in order to render the glass insoluble in water. This water was being continually distilled for use in conductivity experiments in the Physical Chemical Laboratory, and possessed a specific resistance of one megohm.

A portion of this water was thoroughly boiled to remove the dissolved air and the test tube filled to the desired height. The inner tube was not used, but a layer of ice was frozen on the sides of the tube to

about the same thickness as before, the residual water in the center being thrown out. The ice thus formed is very pure, whatever impurities there might have been in the water at the begining being thrown out in the residual water. Two such tubes were prepared and placed in the calorimeter, which was previously filled with cold oil.

Observations were made for the determination of heat capacity, and these are recorded on the following pages. The same experiment was repeated the following day (Feb. 20). The effect of having the oil in contact with the ice was determined by filling the cavity in the center of the ice tubes with oil, and again taking a serie of observations for heat capacity. Any melting of the ice by the oil would be manifest by the increased amount of heat required to produce a given rise in temperature.

Observations for the heat capacity of ice. Feb.19,1903.

Time	Temp.		Time	Temp.	
12:50	-0.525		1:28	-0.135	
51	.520		29	.133	
52	.513		30	.131	
53	.507		31	.130	
54	.500		32	.130	
55	.493		33	.129	
56	.487		34	.128	
57	.481		35	+.126+	
58	.474		36	.124	
59	.469		37	.122	
1:00	.463		38	.120	
01	.458		39	.117	
02	.453+	Current on	40	.115	
03	.435	at 1:02:30	41	.113	
04	.395		42	.112	
05	.355		43	.110	
06	.315	Cell No.329	44	.108+	Current on
07	.278		45		at 1:44:30
08	.261		46	.	Current off
09	.260+	Current off	47	.031	at 1:46:30
10	.259	at 1:07:30	48	.031	
11	.254		49	.031	
12	.252		50	.031	
13	.250		51	.031	
14	.248		52	.031	
15	.245		53	.031	
16	.241		54	.031	
17	.238		55	.031	
18	.235		56	.031+	
19	.231		57	.030	
20	.227		58	.029	
21	.225		59	.028	
22	.222		2:00	.027	
23	.219		01	.026	
24	.217	Current on	02	.025	
25	.213+	at 1:25:30	03	.024	
26	.	Current off	04	.023	
27	.	at 1:27:30	05	.022	

The readings of the thermometer were taken at 60 second intervals, and are recorded in the second column of the preceding table, opposite the corresponding times in the first column. In the third column are given notes regarding the electric current, the time it was on, etc.

On the following pages are the calculations for the change in temperature produced by the current. The observed changes in temperature are on the right hand side of the page, while the calculations for the change in temperature due to the warming from outside influences are made on the left hand side, the result being carried across to the right hand side where it is subtracted from the observed change in temperature to give the change in temperature due to the current alone.

The temperature readings which are used in these calculations are marked with a + in the tables. Similarly, the final results of the calculations are marked with the same sign.

Calculations.

Temp. at 12:50 = .525
" " 1:02 = .453

Change in temp. = .072

" " " per min. = .0060

Temp. at 1:02 = .453
" " 1:09 = .260

Change in temp. = .193

Temp. at 1:09 = .260
" " 1:25 = .213

Change in temp. = .047

" " " per min. = .0030

Mean " " " " " = .0045

" " " " during 7 minutes = .032

Change in temp. due to current = .161 +

Temp. at 1:25 = .213
" " 1:35 = .126

Change in temp. = .087

Temp. at 1:35 = .126
" " 1:44 = .108

Change in temp. = .018

" " " per min. = .0020

(continued)

Mean change in temp. per min. = .0025

" " " " during 4 min. = .010
" " " " " 6 " = .012

" " " " " 10 " = .022

Change in temp. due to current = .085 +

Temp. at 1:44 = .108
" " 1:50 = .031

Change in temp = .077

Temp. at 1:56 = .031
" " 2:05 = .022

Change in temp = .009

" " " per min. = .0010

Mean " " " " " = .0015

" " " " during 3 min. = .0045
" " " " " 9 " = .009

" " " " " 12 " = .013

Change in temp. due to current = .064 +

Observations for the heat capacity of ice. Feb.20.1903.

Time	Temp.		Time	Temp.	
9:00	-1.540		9:35	-0.835	Current off
01	.525		36	.813	at 9:35:30
02	.512		37	.810	
03	.495		38	.808+	
04	.480		39	.803	
05	.465		40	797	
06	.450		41	.791	
07	.435		42	.785	
08	.422		43	.780	
09	.403		44	.772	
10	.396+	Current on	45	.765	
11	.	at 9:10:30	46	.759	
12	.32		47	.753	
13	.27		48	.745	
14	.23		49	.740	
15	.19	Current off	50	.735	
16	.152	at 9:15:30	51	.730+	Current on
17	148		52	.705	at 9:51:30
18	.141		53	.670	
19	.133		54	.625	
20	.125+		55	.585	
21	.115		56	.550	Current off
22	.105		57	.526	at 9:56:30
23	.096		58	.525	
24	.088		59	.525	
25	.076		10:00	.524	
26	.068		01	.521+	
27	.056		02	.517	
28	.043		03	.513	
29	.033		04	.509	
30	1.023+	Current on	05	.505	
31	1.000	at 9:30:30	06	.500	
32	0.96		07	.497	
33	.92		08	.493	
34	.88		09	.488	

Stirring continued but no readings taken for 8 min.

(continued)

continuation. Feb. 20, 1903

Time	Temp.		Time	Temp.	
10:17	-0.454		10:52	-0.060	
18	.453		53	.060	
19	.451		54	.063	
20	.447		55	.064	
21	.443		56	.064	
22	.439		57	.065	
23	.435		58	.065	
24	.430		59	.065	
25	.426+	Current on	11:00	.064	
26	.410	at 10:25:35	01	.064	
27	.365		02	.064	
28	.328		03	.064	
29	.293		04	.063	
30	.257	Current off	05	.062	
31	.233	at 10:30:35	06	.062	
32	.233		07	.060	
33	.233		08	.058+	Current on
34	.233		09	.040	at 11:08:30
35	.233		10	-0.005	Current off
36	.232		11	+0. 015	at 11:10:30
37	.231		12	.016	
38	.227+		13	.016	
39	.225		14	.012	
40	.223		15	.009	
41	.221		16	.007	
42	.219		17	.006	
43	.217		18	.006	
44	.214		19	.006	
45	.211		20	.006	
46	.209		21	.005	
47	.206+	Current on	22	.005	
48	.193	at 10:47:30	23	.005	
49	.150		24	.005	
50	.113	Current off	25	.005	
51	.080	at 10:51:30	26	.005	

Calculations.

Temp. at 9:00 = -1.540
" " 9:10 = 1.396
Change in temp = .144
" " " per min. = .0144

Temp. at 9:10 = -1.396
" " 9:20 = 1.125
Change in temp = .271

Temp. at 9:20 = -1.125
" " 9:30 = 1.028
Change in temp = .097
" " " per min. = .0097
Mean " " " " " = .0120
" " " " during 6 min = .072
" " " " " 4 " = .039
" " " " " 10 " = .111

Change in temp. due to current = .160 +

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Change in temp. per min = .0097

Temp. at 9:30 = -1.028
" " 9:38 = 0.808
Change in temp = .220

Temp. at 9:38 = .808
" " 9:51 = .730
Change in temp = .078
" " " per min = .006
Mean " " " " " = .0078
" " " " during 6 min = .047
" " " " " 2 " = .012
" " " " " 8 " = .059

Change in temp. due to current = .161 +

Temp. at 9:38 = .808
" " 9:51 = .730

Change in temp = .078

" " " per min = .0060

Temp. at 9:51 = .730
" " 10:01 = .521

Change in temp = .209

Temp. at 10:01 = .521
" " 10:09 = .488

Change in temp = .033

" " " per min = .0041

Mean " " " " " = .0050

" " " " during 5 min = .025
" " " " " 5 " = .021
" " " " " 10 " = .046

Change in temp. due to current = .163 +

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Temp. at 10:19 = .451
" " 10:25 = .426

Change in temp = .025

" " " per min = .0042

Temp. at 10:25 = .426
" " 10:38 = .227

Change in temp. = .199

(cont.)

Temp. at 10;38 = .227

" " 10;45 = .211

Change in temp. = .016

" " " per min = .0023

Mean " " " " " = .0033

" " " " during 6 min = .020

" " " " " 7 " = .016

" " " " " 13 " = .036

Change in temp. due to current = .163 +

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Change in temp. per min = .0023

Temp. at 10;47 = .206

" " 10;58 = .065

Change in temp. = .141

Temp. at 10;58 = .065

" " 11;04 = .063

Change in temp = .002

" " " per min = .0003

Mean " " " " " = .0013

" " " " during 5 min = .006

" " " " " 6 " = .002

" " " " " 11 " = .008

Change in temp. due to current = .133 +

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Change in temp. per min = .0003

Temp. at 11;08 = -.059

" " 11;22 = +.005

Change in temp = .063

Change in temp. per min = .0000

Change in temp. due to current = .063 +

Effect of having oil in contact with ice.

The question whether the oil exerted any action upon the ice tending to make it melt was subjected to experiment in the following way. The same ice tubes which were used on the morning of Feb. 20th, and found not to melt below 0°C. were filled with kerosene oil, and the observations repeated that afternoon. The data is given on the following pages and needs ho special explanation, as it is the same arrangement as just described

Oil in contact with the ice.

Observations for the heat capacity of ice. Feb.20.1907.

Time	Temp.		Time	Temp.	
1:50	-0.955		2:18	-0.657	
51	.950		19	.653	
52	.945		20	.648	
53	.939		21	.644	
54	.933		22	.640	
55	.927		23	.635	
56	.920		24	.631	
57	.914		25	.626+	Current on
58	.908		26	.605	at 2:25:30
59	.903		27	.568	
2:00	.898		28	.530	
01	.893+	Current on	29	.490	Current off
02	.870	at 2:01:30	30	.453	at 2:30:30
03	.825		31	.430	
04	.788		32	.430	
05	.745	Current off	33	.431	
06	.709	at 2:06:30	34	.431	
07	.686		35	.432	
08	.684		36	.433+	
09	.685		37	.432	
10	.685		38	.430	
11	.684		39	.428	
12	.682+		40	.423	
13	.678		41	.420	
14	.674		42	.418	
15	.671		43	[illegible]	
16	.6[illegible]		44	[illegible]	
17	.[illegible]2		45	.40[illegible]	

Oil in contact with the ice.

(continuation) Feb. 20, 1903

Time	Temp.	
2:46	-0.406	
47	.	
48	.402	
49	.399	
50	.396	
51	.393	
52	.391	
53	.387	
54	.384	
55	.381	
56	.378+	Current on
57	.350	at 2:56:30
58	.320	
59	.273	
3:00	.245	

Time	Temp.	
3:01	-0.213	Current off
02	.190	at 3:01:30
03	.193	
04	.197	
05	.198	
06	.200	
07	.200	
08	.200+	
09	.199	
10	.199	
11	.199	
12	.198	
13	.197	
14	.194	
15	.193	

Calculations.

Temp. at 1:50 = .955
" " 2:01 = .893

Change in temp = .062

" " " per min = .0057

Temp. at 2:01 = .893
" " 2:12 = .682

Change in temp = .211

Temp. at 2:12 = .682
" " 2:25 = .626
Change in temp = .056

" " " per min = .0043

Mean " " " " " = .0050

" " " " during 6 min = .030
" " " " " 5 " = .021

" " " " " 11 " = .051

Change in temp. due to current = .160 +

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Change in temp. per min = .0043

Temp. at 2:25 = .626
" " 2:36 = .433

Change in temp = .193

Temp. at 2:36 = .433
" " 2:42 = .418
Change in temp = .015
" " " per min = .0025

Mean change in temp per min = .0034

" " " " during 6 min = .020
" " " " " 5 " = .013

" " " " " 11 " = .033

Change in temp. due to current = .160 +

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Temp. at 2:48 = .402
" " 2:56 = .378

Change in temp = .024

" " " per min = .0030

Temp. at 2:56 = .378
" " 3:08 = .200

Change in temp = .178

Temp. at 3:08 = .200
" " 3:15 = .193

Change in temp = .007

" " " per min = .0010

Mean " " " " " = .0020

" " " " during 6 min = .012
" " " " " 3 " = .006

" " " " " 12 " = .018

Change in temp. due to current = .180

The results of the calculations on the preceding pages are summarized in the following table. The second column gives the temperature at which the determination was made, the thermometer reading being corrected for zero point. The numbers in the third column are collected from the preceding pages. In order to render these more comparable, each one is divided by the time (in minutes) that the current was flowing. The results are given in the fourth column and express the change in temperature produced by the current flowing for one minute. Since the current was precisely the same for each determination, the constancy of these numbers shows the constancy of the heat capacity of the calorimeter and its contents, for temperatures ranging from - 1°.4 C. right up to practically 0° C. In the determinations made with the oil in contact with the ice, this constancy was as marked, if not more so, showing that even in this case there was no melting of the ice below 0° C.

Neither is there any increase in the specific heat of ice as it approaches 0° C., as has been main-

tained by some investigators, but it remains a definite constant right up to the point at which the ice melts. That is, such is the case for this very pure ice, as is shown by the constancy of its heat capacity, and this is what would be expected since ice is a crystalline substance. As already pointed out, if there are impurities in the ice, even in very small amounts, an apparent increase in its specific heat may be produced by the lowering of the melting point of some portions of the ice.

Table 11. Heat capacity of ice.

Date	Actual Temp.	Change in Temp.	Change in Temp. per min.	
Feb. 19	- 0.48	.161	.0322	
	- 0.24	.065	.0325	
	- 0.06	.064	.0320	With ice mantles
Feb. 20	- 1.43	.160	.0320	in glass test tubes
	- 1.03	.161	.0322	
	- 0.73	.163	.0326	
	- 0.23	.163	.0326	
	- 0.09	.133	.0332	
	- 0.02	.063	.0315	
Feb. 20	- 0.92	.160	.0320	Ice mantles filled
	- 0.66	.160	.0320	with kerosene.
	- 0.23	.160	.0320	

Effect of mixing water and oil.

When the ice melts the resulting water is stirred up with the oil, and the question arrises whether this mixture of the two liquids is accompanied by any thermal change. The point was subjected to experiment in the following way. About 300 cc. of oil was placed in the calorimeter, and about 50 cc. of water, the latter being in a large test tube. A glass rod with a brass tip was placed within the test tube so that the bottom could be broken from the outside. This arrangement was allowed to stand over night to assume an equilibrium temperature. The following observations were taken the next morning.

It will be noticed that after the test tube was broken and the water allowed to flow out and mingle with the oil, there appears to be a rise in temperature of 0.001 C. In order to see whether this was due to any action between the oil and water, or only to the mechanical energy put forth in breaking the tube, the motion of breaking the test tube was repeated as shown

in the table of observations on the following page. In this case also there is a rise of temperature of the same amount as before, and since in this there is no question of water mixing with the oil, this increase in temperature, if real, must be due to the mechanical energy expended in the process of breaking the tube.

It is certainly safe to assert that there is no production or absorption of heat when the oil and water are stirred up together.

Observations on mixing water and oil.   Mar. 12, 1903.

Time.	Temp.		Time	Temp.	
1:50	+0.310		2:25	+0.297	
51	.304		26	.296	
52	.303		27	.296	
53	.300		28	.296	
54	.300		29	.296	
55	.300		30	.296	
56	.300		31	.295	
57	.300		32	.295	
58	.298		33	.295	
59	.298		34	.295	
2:00	.298		35	.295	
01	.297		36	.295	
02	.297		37	.295	
03	.297		38	.295	
04	.297		39	.294	
05	.297		40	.294	
06	.	Test tube	41	.294	
07	.297	broken	42	.294	
08	.297		43	.294	
09	.297		44	.	Motion of
10	.298		45	.295	breaking
11	.298		46	.295	test tube
12	.298		47	.295	repeated.
13	.298		48	.295	
14	.298		49	.295	
15	.298		50	.295	
16	.298		51	.295	
17	.298		52	.295	
18	.297		53	.295	
19	.297		54	.295	
20	.297		55	.295	
21	.297		56	.295	
22	.297		57	.295	
23	.297		58	.295	
24	.297		59	.295	

EXPERIMENTS WITH PURE ICE.

In view of the preceding investigations, all further experiments were made with ice formed from the pure distilled water. About half a liter of this water was boiled for twenty or thirty minutes to remove as much of the dissolved air as possible. The remaining 800 cc. of water was poured into a beaker which it nearly filled, and when cooled somewhat the beaker was set in a freezing mixture of fine ice and salt. If supercooling of the water was allowed, ice crystals would suddenly form throughout the water. To prevent this form of ice and obtain it in a firm compact layer a small bit of ice was frozen to the side of the beaker just above the surface of the water, and below the surface of the freezing mixture outside. Here it would remain till the outer layer of water was cold enough to freeze. Then a film of ice was seen to start from the bit on the glass and spread over the inner surface of the beaker. After an hour or two this layer of ice reached a thickness of nearly a

centimeter. The remaining water was discarded, and the ice removed from the beaker by slightly warming the outside. This cup of ice was taken to the coldest place available and cut into cubes ranging from one to one fourth cubic centimeter in size. These pieces were dropped into another beaker in a freezing mixture where they were cooled several degrees below 0°C., and thus freed from any clinging water either on the surface or interior. The ice was then weighed and quickly transferred to the calorimeter as already described.

Eight determinations of the heat of fusion of this ice were made on as many different days, one entire day being required to make one determination. During the greater part of this period the weather was below 0°C. in the morning, which greatly facilitated the handling and weighing of the ice.

The amounts of ice used in each of these experiments is shown in the following table.

Table III. Amounts of ice used in the experiments.

Date	Weight of Ice		
	Beaker + Ice	Beaker	Ice
Feb. 27	287.86	186.49	101.37
Feb. 28	292.78	190.43	102.35
Mar. 2	274.82	194.59	80.23
Mar. 3	283.12	194.67	88.45
Mar. 4	307.43	194.41	113.02
Mar. 5	289.91	198.84	91.07
Mar. 6	302.37	200.09	102.28
Mar. 7	275.73	189.31	85.92

Experiment of Feb. 24th.

Heat capacity with ice.

With this very pure ice which it had been shown could be warmed right up to 0 C. without any melting or apparent increase of its specific heat, it was expected that the initial temperature could safely be brought to within a few tenths of a degree of 0° C. Nevertheless there appeared unmistakable evidences that if the temperature was too near 0° C. a small amount of melting of the ice would be caused by the current used in the preliminary experiments to determine the heat capacity of the calorimeter with the ice. Such determinations were, therefore, made only at temperatures below - 1° C.

In this determination of the heat capacity, the current, as already stated, was that which would flow through the heating coil when its terminals were maintained at a difference of potential equal to the E. M. F., E, of one standard cell. The heat produced is then given by the formula, $\frac{E^2t}{R}$, where R is the resistance of the coil and t the number of seconds that the current was flowing.

Observations for heat capacity. Feb. 24, 1903

Time	Temp.		Time	Temp.	
9:50	-1.900		10:16	-1.298	
51	.880		17	.286	Current on
52	.863		18	.265	at 10:17:30
53	.843		19	.233	
54	.824		20	.204	
55	.804		21	.170	
56	.785	Current on	22	.143	
57	.760	at 9:56:30	23	.112	
58	.722		24	.085	
59	.680		25	.054	
10:00	.650		26	1.025	
01	.614		27	0.997	Current off
02	.575		28	.976	at 10:27:30
03	.543		29	.965	
04	.507		30	.957	
05	.475		31	.950	
06	.443	Current off	32	.940	
07	.415	at 10:06:30	33	.942	
08	.402		34	.924	
09	.391		35	.914	
10	.377		36	.905	
11	.362		37	.897	
12	.352		38	.889	
13	.338		39	.882	
14	.326		40	.873	
15	.310		41	.	

Note - The amount of ice used in this experiment was 103.26 grams.

Calculations.

Temp. at 9:50 = -1.900
" " 9:56 = 1.785

Change in temp = .115

" " " per min = .0192

Temp. at 9:56 = -1.785
" " 10:07 = 1.415

Change in temp. = .370

Temp. at 10:07 = -1.415
" " 10:17 = 1.286

Change in temp = .129

" " " per min = .0129

Mean " " " " " = .0160

" " " " during 11 minutes = .176

Change in temp due to current = .194

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Change in temp. per min = .0129

Temp. at 10:17 = -1.286
" " 10:29 = 0.965

Change in temp. = .321

Temp. at 10:29 = -.965
" " 10:40 = .873
Change in temp = .092
" " " per min = .0084
Mean " " " " " = .0107
" " " " " during 12 minutes = .128
Change in temp. due to current = 193

In the two determinations of heat capacity given above, that same amount of heat was supplied by the current, resulting in a net change of temperature of 0.194 and 0.193 respectively. These numbers agree as closely as could be expected since the temperatures themselves were read only to thousandths of a degree. They further show that the specific heat of the combined apparatus, if the term can be allowed, is the same at - 1.6 C. and at - 1.0 C.

The amount of heat generated by the current is

$$H = \frac{E^2 t}{R} = \frac{(1.0191)^2 \times 600}{4.966} = 125.47 \text{ joules.}$$

Since this amount of heat corresponds to a mean change of temperature of 0.1935, for a change of one degree the heat would be

$$\text{Joules per degree} = \frac{125.47}{0.1935} = 648.$$

The remainder of this experiment is necessarily discarded as the current used in melting the ice was too variable to measure, and it could not be kept constant by varying the controling resistance. The difficulty was finally located in a defective storage cell which was replaced by one in better condition.

The preceding determination of heat capacity is, however, complete in all respects and it is here given for use in calculating the corrections for some of the later experiments in which it was not possible to obtain a direct determination of heat capacity.

Experiment of Feb. 27th.

Observations of the experiment of Feb. 27, 1903

Part 1. Heat capacity with ice.

Time	Temp.	
12:50	-1.610	
51	.595	
52	.482	
53	.569	
54	.554	
55	.542	
56	.523	
57	.515	
58	.502	
59	.490	Current on
1:00	.475	at 12:59:30
01	.444	
02	.413	
03	.382	
04	.351	Current off
05	.329	at 1:04:30
06	.318	
07	.307	
08	.297	
09	.288	
10	.276	
11	.268	
12	.266	
13	.250	
14	.240	
15	.230	

Time	Temp.	
1:16	-1.220	
17	.211	
18	.203	
19	.194	
20	.184	
21	.175	Current on
22	.160	at 1:21:30
23	.133	
24	.107	
25	.080	
26	.055	Current off
27	.033	at 1:26:30
28	.027	
29	.018	
30	.011	
31	1.004	
32	0.997	
33	.989	
34	.983	
35	.976	
36	.970	

These readings were continued for 25 minutes without interruption.

Observations of the experiment of Feb. 27, 1903

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
2:01	-.803		2:31	+.54	
02	.793		32	.57	
03	.792		33	.68	
04	.780		34	.60	
05	.777		35	.71	
06	.767		36	.70	
07	.762		37	1.05	Current off
08	.753+	Current on	38	.95	at 2:37:00
09	-.25	at 2:08:30	39	.90	
10	+.23		40	.900	
11	.25		41	.900	
12	.26		42	.898	
13	.25	Cell No.329	43	.897	
14	.25	Q = 10,000	44	.893	
15	.25	R = 1114	45	.887+	
16	.27	d = -1.00	46	.883	
17	.27		47	.877	
18	.27		48	.872	
19	.31		49	.865	
20	.30		50	.855	
21	.30		51	.845	
22	.30		52	.845	
23	.37		53	.843	
24	.38		54	.837	
25	.37		55	.832	
26	.40		56	.827	
27	.44		57	.823	
28	.44		58	.817	
29	.47		59	.812	
30	.45		3:00	807	

Observations of the experiment of Feb. 27, 1903.

Part III. Heat capacity with water

Time	Temp.		Time	Temp.	
3:01	+.800	Current on	3:33	+.868	
02	.805	at 3:00:30	34	.862	
03	.817		35	.857	
04	.828		36	.850	
05	.835	Current off	37	.847	
06	.841	at 3:05:32	38	.843	
07	.842		39	.840	
08	.842		40	.835	
09	.835		41	.830	
10	.832		42	.826	
11	.828		43	.821	Current on
12	.821		44	.818	at 3:43:30
13	.817		45	.820	
14	.812		46	.830	
15	.807		47	.838	
16	.803		48	.852	
17	.799		49	.862	
18	.795	Current on	50	.869	
19	.793	at 3:18:30	51	.878	
20	.797		52	.887	
21	.807	Cell No.331	53	.897	Current off
22	.818		54	.903	at 3:53:30
23	.825		55	.904	
24	.834		56	.904	
25	.845		57	.898	
26	.853		58	.893+	
27	.862		59	.887	
28	.872	Current off	4:00	.883	
29	.873	at 3:28:30	01	.878	
30	.873		02	.874	
31	.873+		03	.870	
32	.872		04	.866	
			05	.862	

Calculations for Part 1.

Temp. at 12:50 = 1.610

" " 12:59 = 1.490

Change in temp = .120

" " " per min = .0133

Temp. at 12:59 = 1.490

" " 1:07 = 1.307

Change in temp = .183

Temp. at 1:07 = 1.307

" " 1:15 = 1.230

Change in temp = .077

" " " per min = .0096

Mean " " " " " = .0114

" " " " during 6 min = .068

" " " " " 2 " = .019

" " " " 8 " = .087

Change in temp. due to current = .096

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Temp. at 1:16 = 1.220

" " 1:21 = 1.175

Change in temp = .045

" " " per min = .0090

Temp. at 1:21 = 1.175

" " 1:30 = 1.011

Change in temp = .164

Temp. at 1:30 = 1.011

" " 1:36 = .970

Change in temp = .041

" " " per min = .0068

Mean " " " " " = .0079

" " " " during 6 min = .047

" " " " " 3 " = .020

" " " " 9 " = .067

Change in temp due to current = .097

Calculations for Part II.

During this part of the experiment the current was maintained at such a value that the fall of potential through the standard half ohm coil was just equal to the E. M. F. of the standard cell No. 329. (= 1.0193 volts). Hence,

$$\text{Current} = \frac{E}{R} = \frac{1.0193}{.50008} = 2.03827 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with P = 1114 = 1114.82 ohms. At this value the mean deflection of the galvanometer was -1.00 divisions, and since a change in P of one ohm corresponds to a deflection of 8 divisions, this deflection corresponds to a change of -0.12 ohm. Hence to have produced an exact balance. P should have been 1114.70 ohms. This gives

$$V = \frac{P + Q}{P} = \frac{11064.4}{1114.70} = 10.1175 \text{ volts.}$$

The current flowing through the potentiometer is

$$\frac{10.1175}{11064.4} = 0.00091 \text{ amperes.}$$

Therefore the current through the heating coil is.

$$2.03827 - 0.00091 = 2.03736 \text{ amperes.}$$

Since this current was flowing 1710 seconds the total heat is.

$$EIt = 35248 \text{ joules}$$

Calculations for Part III.

Temp. at 3:13 = .891
" " 3:18 = .795
Change in temp = .096
" " " per min = .0043

Temp. at 3:18 = .795
" " 3:31 = .877
Change in temp = .082

Temp. at 3:31 = .877
" " 3:43 = .821
Change in temp = .056
" " " per min = .0047
Mean " " " " " = .0045
" " " " during 13 minutes = .058

Change in temp. due to current = .140 +

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Change in temp. per min = .0047

Temp. at 3:43 = .821
" " 3:58 = .893
Change in temp = .072

Temp. at 3:58 = .893
" " 4:05 = .862
Change in temp = .031
" " " per min == .0044
Mean " " " " " = .0045

" " " " during 15 min = .068

Change in temp. due to current = .140

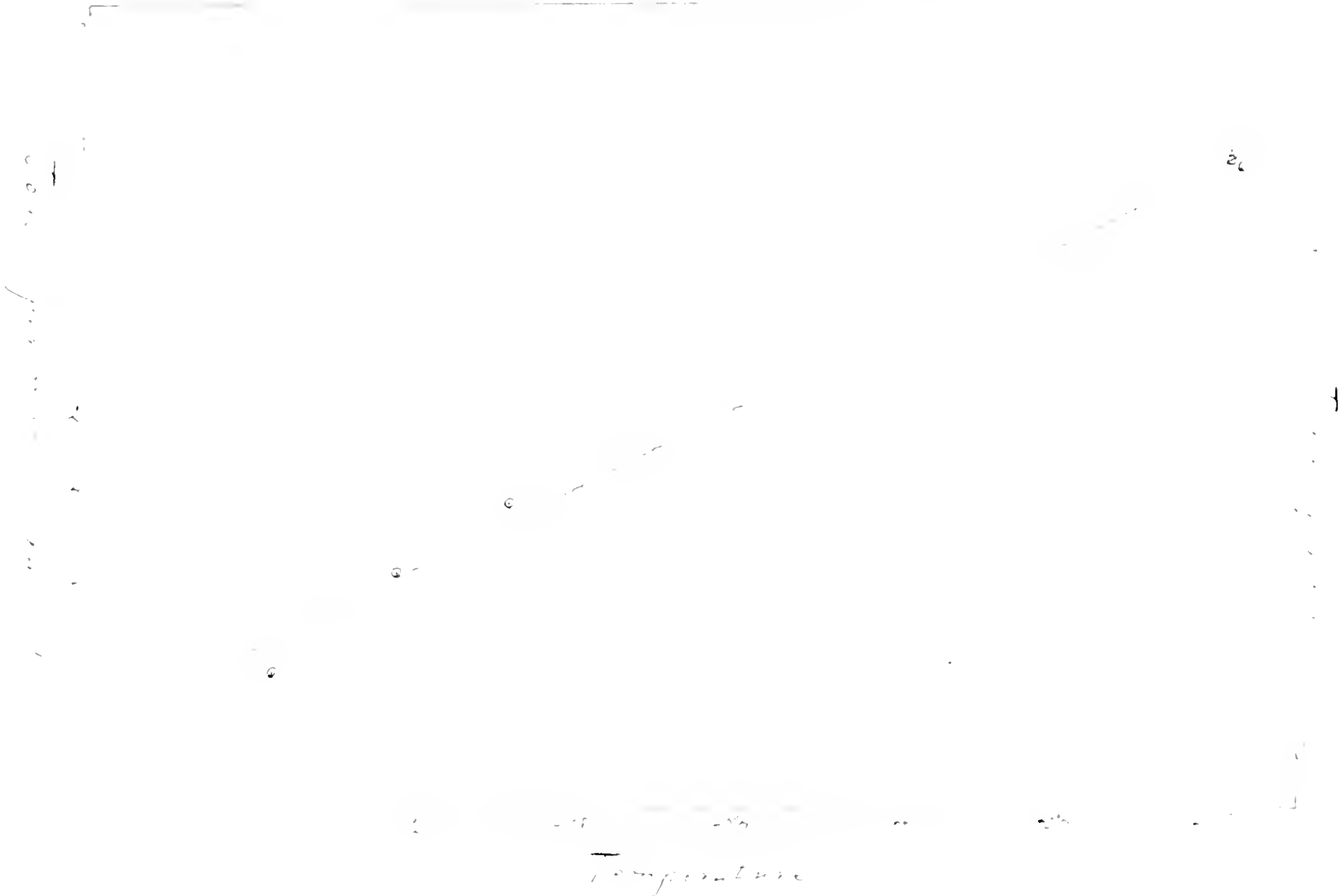
In the determinations of heat capacity, both with ice and with water, the same current was used as on Feb. 24th., namely that which would flow through the heating coil when its terminals were maintained at a potential difference equal to the E. M. F. of the standard cell No. 331. In Part I. the current flowed for five minute periods, and since the amount of ice is nearly the same as for Feb. 24. the change in temperature should be one half as great, as it is very closely, the two results being 0°.096 and 0°.097 for the change produced by 62.73 joules. Hence

$$\text{(With ice) Joules per degree} = \frac{62.73}{.0965} = 650$$

The same current was employed in Part II. but for ten minute periods, hence giving 125.47 joules. The resulting change in temperature is .140. Hence.

$$\text{(With water) Joules per degree} = \frac{125.47}{.140} = 896.$$

Fig. 172



Correction for radiation, conduction, convection, stirring, etc.

The heat lost (or gained) to the calorimeter by the combined action of these causes is determined by the rate of cooling (or warming) experienced when no heat is being supplied by the current. These rates have been observed and recorded in connection with the determination of heat capacity. Expressed in joules per minute, they are plotted on the accompanying sheet as ordinates, against the corresponding temperatures as abscissae. The resulting curve gives the loss at any temperature.

The "duration" of this experiment was 37 minutes, and the average temperature during this interval was 0.51 °C. From the curve, the loss of heat at this temperature is 2.45 joules per minute. Hence the total loss is,

$$2.45 \times 37 = 91 \text{ joules.}$$

Summary of experiment for Feb. 27th.

Total heat supplied by the current = 35248 joules.

Initial temperature = -0.753

" " corrected for zero = -0.788

Heat to raise calorimeter and contents from -0.788 to 0 C

= 650 x 0.788 = 512 joules.

Final temperature = +0.887

" " corrected for zero = +0.852

Heat to raise calorimeter from 0 C. to +0.852

= 896 x 852 = 763 joules

Heat lost by radiation, convection, conduction, etc.,

= 91 joules.

Total correction = 512 + 763 + 91 = 1366 joules

Total amount of heat required to melt 104.27 grams of ice

= 35248 - 1366 = 33882 joules

= 324.94 joules per gram.

This experiment appears complete in every respect. The heat capacity was directly determined both before and after the experiment. The current was on for just the right time to melt all the ice and leave the final temperature a few tenths of a degree above 0° C., thus making possible a short duration. The weight given to this experiment is therefore the full amount of 6 points.

Experiment of Feb. 28th.

Part 1. Heat capacity with ice.

The amount of ice used in this experiment was very nearly the same as on Feb. 24th., being 102.35 grams instead of 102.24 grams. Therefore, as no direct determination of the heat capacity could be made owing to insufficient temperature range, no appreciable error can be introduced by assuming the same value as determined on Feb. 24th., viz.,

Joules per degree = 648

The observations during the period of melting the ice are given on the following page, the arrangement being exactly similar to those already given.

Observations of the experiment of Feb. 23, 1903.

Part II. Melting the ice. Part III, heat capacity.

Time	Temp.		Time	Temp.	
After stirring 30 min.					
1:50	-.701		2:27	-.68	
51	.679		28	.674	
52	.672		29	.677+	
53	.667		30	.676	
54	.661		31	.675	
55	.657		32	.678	Vigorous stir-
56	.652	Current on	33	.679	ring to show
57	-.20	at 1:56:30	34	.679	its effect.
58	+.20		35	.679	
59	.27		36	.677	
2:00	.27		37	.674	
01	.25		38	.668	
02	.27		39	.666	
03	.32	Cell No.399	40	.662	
04	.28	S = 10,000	41	.657	
05	.30	P = 1113	42	.653	
06	.30	d = 0	43	.649	
07	.33		44	.646	
08	.42		45	.643	
09	.33		50	.623	
10	.30		51	.618	
11	.30		52	.614	Current on
12	.31		53	.610	at 2:53:30
13	.37		54	.72	Current off
14	.37		55	1.330	at 2:54:02
15	.36		56	1.345	
16	.35		57	1.328	
17	.42		58	1.310	
18	.40		59	1.295+	
19	.37		3:00	1.284	
20	.53		01	1.275	
21	.45		02	1.264	
22	.50		03	1.253	
23	.57		04	1.243	
24	.73		05	1.233	
25	.98	Current off	06	1.223	
26	.36	at 2:25:00			

Calculations for Part II.

The standard cell used on this day was No. 399. (E. M. F. = 1.0193 volts), and hence the current through the standard coil was

$$\frac{1.0193}{.50008} = 2.03827 \text{ amperes}$$

The nearest balance of the potentiometer was obtained with P =1113 = 1113.79 ohms, this value giving a mean deflection of zero. Hence this gives,

$$1.0193 \times \frac{11063.5}{1113.79} = 10.1249 \text{ volts}$$

The current through the potentiometer is,

0.00091 ampere.

giving for the current through the heating coil,

2.03827 - 0.00091 = 2.03736 amperes.

The current was flowing for 1710 seconds, giving a total amount of heat of,

35274 joules.

Calculations for Part III.

Temp. at 2:45 = .643
" " 2:53 = .610

Change in temp = .033

" " " per min = .0041

Temp. at 2:53 = .610
" " 2:59 = 1.295

Change in temp = .685

Temp. at 2:59 = 1.295
" " 3:06 = 1.223

Change in temp = .072

" " " per min = .0103 at 1.26
= .0109 at 1.33 C.

Mean " " " " " = .0075

" " " " during 2 min = .0150
" " " " " 4 " = .0436
" " " " " 6 " = .059

Change in temp. due to current = .744

The current used in this part of the experiment was the same as employed for melting the ice. As it was flowing 32 seconds the heat generated is,

2.03736 x 10.1249 x 32 = 660 joules.

Therefore, (with water),

$$\text{Joules per degree} = \frac{660}{.744} = 887.$$

<u>Correction for radiation, conduction, convection, stirring, etc.</u>

The rates of cooling determined at different temperatures are plotted on the adjoining curve in terms of joules per minute.

The duration of this experiment was 33 minutes, and the average temperature during this interval was +0°.41 C. From the curve, the loss of heat at this temperature is 2.10 joules per minute. Hence the total loss is,

$$2.10 \times 33 = 69 \text{ joules.}$$

Summary of Experiment of Feb. 28th.

Total heat supplied by the current = 35274 joules.

Initial temperature = -0.652.

" " corrected for zero = -0.687

Heat to raise calorimeter and contents from -.687 to 0 C

= 648 x 0.687 = 445 joules.

Final temperature = +0.677

" " corrected for zero = +0.642.

Heat to raise calorimeter and contents from 0 C.to +.642

= 887 x .642 = 569 joules.

Heat lost by radiation, convection, conduction, etc.

= 69 joules.

Total correction = 445 + 569 + 69 = 1083 joules.

Total heat required to melt 102.35 grams of ice

= 35274 - 1083 = 34191 joules

= 334.06 joules per gram.

In this experiment there is a single point only in which it falls behind the preceding one in the matter of weighting, - and that is in the fact of no direct determination of heat capacity preceding the main experiment. There is room for no serious doubt of the validity of thus assuming the value of heat capacity determined one day as applicable to the same masses on another day,- else the entire experiment would have been discarded. However, in the weighting there is this point lacking, giving for this experiment the value of 5 points.

Experiment of Mar. 2nd.

Observations of the experiment of Mar. 2nd.

Part 1. Heat capacity with ice.

Time	Temp.		Time	Temp.	
1:10	-2.384		1:45	-1.556	
11	.353		46	.527	
12	.332		47	.495	
13	.313		48	.465	
14	.297		49	.435	
15	.280		50	.406	Current off
16	.260		51	.383	at 1:50:30
17	.242		52	.373	
18	.228		53	.365	
19	.210		54	.356	
20	.193	Current on	55	.345	
21	.168	at 1:20:30	56	.337	
22	.133		57	.328	
23	.097		58	.318	
24	.060	Cell No.381	59	.310	
25	2.024		2:00	.300	Current on
26	1.987		01	.285	at 2:00:30
27	.956		02	.260	
28	.926		03	.230	
29	.885		04	.202	
30	.852	Current off	05	.176	
31	.824	at 2:30:30	06	.145	
32	.809		07	.117	
33	.787		08	.093	
34	.785		09	.068	
35	.772		10	.040	Current off
36	.758		11	.020	at 2:10:30
37	.743		12	.014	
38	.730		13	1.007	
39	.716		14	1.002	
40	.703	Current on	15	.996	
41	.688	at 1:40:30	16	.992	
42	.653		17	.986	
43	.623		18		
44	.587		19	.	

Observations of the experiment of Mar. 2nd.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
2:20	-.964		2:55	+.077	
21	.958		56	.082	
22	.952	Current on	57	.089	
23	-.55	at 2:22:30	58	.096	
24	+.27		59	.104	
25	.40		3:00	.108	
26	.37	Cell No.329	01	.114	
27	.36	Q = 10,000	02	.122	Small current
28	.43	P = 1114	03	.124	off at 3:02:30
29	.46	d = -0.37	04	.124	
30	.48		05	.118	
31	.44		06	.110	
32	.52		07	.105	
33	.60		08	.100	
34	.61		09	.095	Small current
35	.65		10	.092	at 3:09:30
36	.75		11	.095	
37	.68		12	.107	
38	.68		13	.118	
39	.83		14	.129	
40	.84		15	.140	
41	.83		16	.152	
42	.84		17	.167	
43	.85		18	.178	
44	.95	Current off	19	.190	Small current
45	1.05	at 2:44:45	20	.200	off at 3:19:30
46	.70		21	.200	
47	.35		22	.200	
48	.23		23	.200+	
49	.17		24	.198	
50	.17		25	.197	
51	.10		26	.196	
52	.085	Small current	27	.195	
53	.085	on at 2:52:30	28	.194	
54	.085	Cell No.331	29	.192	

Observations of the experiment of Mar. 2nd.

Part III. Heat capacity with water.

Time	Temp.		Time	Temp.	
3:29	+.192-	Current on	3:59	+.344	
30	.192	at 3:29:30	4:00	.358	
31	.190		01	.368	
32	.210		02	.382	
33	.223		03	.395	
34	.237	Cell No.331	04	.407	
35	.249		05	.418	
36	.263		06	.430	
37	.276		07	.443	
38	.288		08	.454	
39	.300	Current off	09	.466	
40	.309	at 3:39:30	10	.478	
41	.312		11.	.490	
42	.312		12	.501	
43	.312		13	.512	Current off
44	.311+		14	.523	at 4:13:30
45	.308		15	.523	
46	.305		16	.522	
47	.303		17	.519+	
48	.301		18	.515	
49	.298		19	.511	
50	.297		20	.507	
51	.294		21	.503	
52	.292		22	.499	
53	.289+	Current on	23	.495	
54	.289	at 3:53:30	24	.492	
55	.289		25	.488	
56	.305		26	.485	
57	.318		27	.481	
58	.333		28	.478	

Calculations for Part I.

Temp. at 1:10 = -2.353
" " 1:20 = 2.193
Change in temp = .160
" " " pre min = .0178

Temp. at 1:20 = -2.193
" " 1:31 = 1.824
Change in temp = .369

Temp. at 1:31 = -1.824
" " 1:40 = 1.703
Change in temp = .121
" " " per min = .0134
Mean " " " " " = .0156
" " " " during 11 min = .171

Change in temp due to current = .198

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Change in temp per min = .0134

Temp. at 1:40 = -1.703
" " 1:52 = 1.373
Change in temp = .330

Temp. at 1:52 = 1.373
" " 2:00 = 1.300
Change in temp = .073
" " " per min = .0091
Mean " " " " " = .0112
" " " " during 11 min = .123
" " " " " 1 " = .009
" " " " 12 " = .132

Change in temp. due to current = .198

Calculations for Part I. (cont.)

Change in temp. per min = .0091

Temp. at 2:00	=	-1.300
" " 2:11	=	1.020
Change in temp =		.280

Temp. at 2:11	=	-1.020
" " 2:17	=	0.936

Change in temp = .036

" " " per min = .0060

Mean " " " " " = .0075

" " " " during 11 min = .082

Change in temp. due to current = .198

These three results agree closely, again showing the constancy of the specific heat over the range from -2°.2 C. to -1°.0 C. The same current was used as before thus giving 125.47 joules in ten minutes. The resulting change in temperature , -°.198, is greater than in the preceding cases, as it should be since there was 20 gms. less ice in the calorimeter. Therefore,

$$\text{Joules per degree} = \frac{125.47}{0.198} = 634 \quad \text{(with ice)}$$

Calculations for Part II.

After the melting current was stopped there remained more ice than could be melted by the oil in cooling to 0° C. Therefore the small current previously used was passed for sufficient time to melt the remaining ice. While this process increases the total length of the experiment, no large errors are introduced as the extra current is exactly determined, and the losses due to radiation, etc., are very small owing to the low temperature of the calorimeter for the last two thirds of the experiment.

The standard cell used for the measurement of the larger current was No. 329, (= 1.0193 volts), and hence the current through the standard half ohm coil was

$$\frac{1.0193}{.50003} = 2.03827 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with $P = 1114 = 1114.82$ ohms, this value giving a mean deflection of - 0.37 divisions, corresponding to - 0.04 ohm. Hence the value of P which would have given an exact balance is $1114_{.78}$ ohms. This gives,

$$1.0193 \; \frac{11064.6}{1114.78} \; 10.1169 \text{ volts}$$

The current through the potentiometer is

$$0.00091 \text{ ampere.}$$

giving for the current through the heating coil.

$$2.03827 - 0.00091 = 2.03736 \text{ amperes.}$$

This current was flowing for 1335 seconds, giving a total amount of heat of

$$27517 \text{ joules.}$$

The smaller current was flowing for 20 minutes, giving.

$$12.547 \times 20 = 251 \text{ joules.}$$

Hence the total heat supplied by the current is

$$27517 + 251 = 27768 \text{ joules.}$$

Calculations for Part III.

Temp. at 3:24 = +.198
" " 3:29 = .192
Change in temp = .006
" " " per min = .0012

Temp. at 3:29 = .192
" " 3:44 = .311
Change in temp = .119

Temp. at 3:44 = .311
" " 3:53 = .289
Change in temp = .022
" " " per min = .0024
Mean " " " " " = .0018
" " " " during 8 min = .014
" " " " " 8 " = .019
" " " " " 16 " = .033

Change in temp. due to current = .152

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Change in temp. per min = .0024

Temp. at 3:53 = .289
" " 4:17 = .519
Change in temp = .230

Temp. at 4:17 = .519
" " 4:22 = .478
Change in temp = .041
" " " per min = .0038
Mean " " " " " = .0031

" " " " during 24 min = .074

Change in temp. due to current = .304

In this determination of heat capacity with water the same current as heretofore was used, it being allowed to flow for ten minutes in one case and twenty in the other and giving twice the change in temperature in the latter case.

The amount of heat generated by this current in ten minutes is therefore 125.47 joules, and the change in temperature produced is 0°.152 C. Therefore,

$$\text{Joules per degree} = \frac{125.47}{0.152} = 825 \quad \text{(with water)}$$

Correction for radiation, conduction, convection, stirring, etc.

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.

The "duration" of this experiment was 61 minutes, and the average temperature during this interval was + 0°.31 C. From the curve, the loss of heat at this temperature is 2.50 joules per minute. Hence the total loss of heat is,

2.50 x 61 = 153 joules.

Weighting

As the first application of the current in this experiment was insufficient to melt the ice it was necessary to supply additional heat. This resulted in a prolonged duration of the experiment.

The heat capacity, however, was determined both at the beginning and the end of the experiment, and the rate of cooling was perfectly definite at the end.

Thus in weighting this experiment has 3 points.

Total heat supplied by the current = 27768 joules.

Initial temperature = -0.952.

" " corrected for zero = -0.987.

Heat to raise calorimeter and contents from -.987 to 0 C

= 634 x .987 = 626 joules.

Final temperature = +0.200

" " corrected for zero = +0.165.

Heat to raise calorimeter and contents from 0 C. to +.165

= 825 x .165 = 136 joules.

Heat lost by radiation, conduction, convection, etc.,

= 153 joules.

Total correction = 626 + 136 + 153 = 915 joules.

Total heat required to melt 80.23 grams of ice.

= 27768 - 915 = 26853 joules.

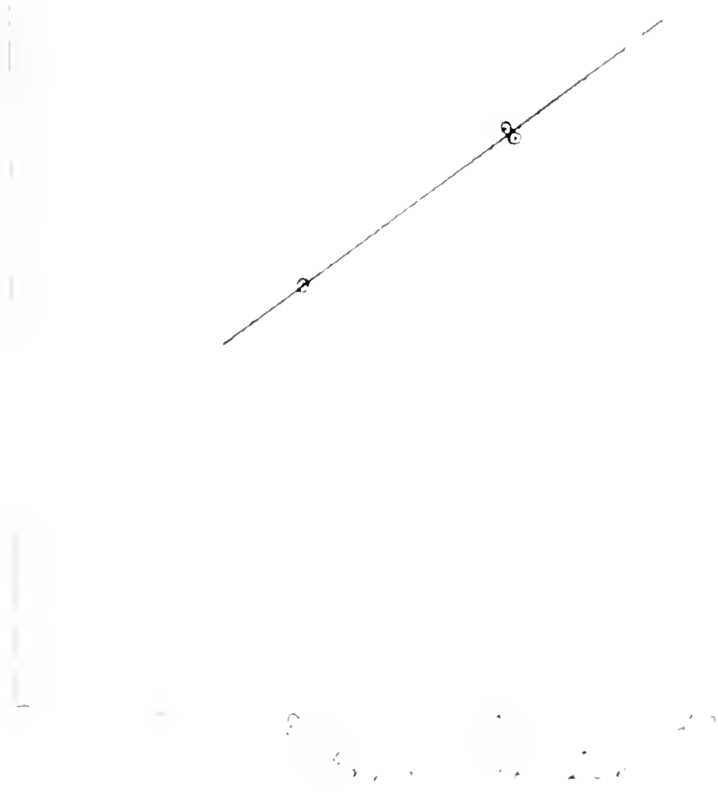
= 334.69 joules per gram of ice.

Experiment of Mar. 3rd.

Part I. Heat capacity with ice.

The initial equilibrium temperature of this experiment was about -1° C., and the determination of heat capacity therefore not allowable. Of course this could not be very different from the heat capacity on previous days, as the smae calorimeter and the same amount of oil was used each time, and approximately the same amount of ice. The determinations of Feb. 24, Feb. 27, and Mar. 2 were all very satisfactory, and these are plotted as ordinates against the corresponding amounts of ice as abscissae. The resulting curve is given herewith, and for the short range required of it, it gives the the heat capacity with varying amounts of ice very exactly. The amount of ice used on Mar. 3rd. was 28.45 grams. The corresponding heat capacity is

Joules per degree = 640 (with ice)



Observations of the experiment of Mar. 3. 1903.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
After stirring half hour			2:05	.213	
1:30	-.705		06	.180	
31	.697		07	.155	
32	.692		08	.143	
33	.685		09	.143	
34	.679		10	.116	
35	.674	Current on	11	.109	
36	-.30	at 1:35:30	12	.105	
37	+.35		13	.097	
38	.55		14	.095	
39	.55	Cell No.329	15	.089	Small current
40	.55	C = 10,000	16	.090	on at 2:15:30
41	.55	P = 1114	17	.091	
42	.57	d = -1.62	18	.100	
43	.56		19	.110	Cell No. 331
44	.58		20	.118	
45	.57		21	.127	
46	.57		22	.135	
47	.65		23	.147	
48	.63		24	.157	Small current
49	.65		25	.166	off at 2:24:30
50	.70		26	.167	
51	.65		27	.167	
52	.71		28	.166	
53	.80		29	.162	
54	.77		30	.159+	
55	.92		31	.157	
56	.39		32	.156	
57	.100		33	.154	
58	.101		34	.153	
59	.108	Current off	35	.152	
2:00	.120	at 1:59:50	36	.150	
01	.93		37	.149	
02	.72		38	.149	
03	.40		39	.149	
04	.27		40	.149	

Observations of the experiment of Mar. 3rd.

Part 1-1. Heat capacity with water.

Time	Temp.		Time	Temp.	
2:41	+.148		3:10	+.280	
42	.148		11.	.279	
43	.148		12	.278	
44	.148		13	.277	
45	.148	Current on	14	.276	
46	.148	at 2:45:30	15	.275	Current on
47	.157		16	.275	at 3:15:30
48	.175		17	.283	
49	.192	Cell No. 331	18	.297	
50	.203		19.	.309	
51	.220		20	.323	
52	.235		21	.338	
53	.248		22	.353	
54	.262		23.	.266	
55	.275	Current off	24	.380	
56	.288	at 2:55:30	25	.392	Current off
57	.290		26	.404	at 3:25:30
58	.290		27	.404	
59	.290+		28	.404	
3:00	.289		29	.405+	
01	.288		30	.404	
02	.287		31	.403	
03	.286		32	.401	
04	.285		33	.398	
05	.284		34	.395	
06	.283		35	.394	
07	.282		36	.392	
08	.281		37	.390	
09	.281		38	.388	

Calculations for Part II.

In this experiment again a bit of ice remained unmelted after the large current was stopped and the oil cooled to nearly 0°C. It was therefore necessary to apply the small current for a few minutes.

The standard cell No. 329 (= 1.0193 volts) was used in the measurement of the current, which was

$$\frac{1.0193}{.50008} = 2.03827 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with P = 1114 = 1114.82 ohms, this value giving a mean deflection of - 1.62 divisions, corresponding to - 0.20 ohm. Hence the value of P which would have given an exact balance is 1114.62 ohms. This gives

$$1.0193 \frac{11064.3}{1114.62} = 10.1181 \text{ volts}$$

The current through the potentiometer is

$$0.00091 \text{ ampere.}$$

giving for the current in the heating coil,

$$2.03827 - 0.00091 = 2.03736 \text{ amperes.}$$

This current was flowing for 146[illegible] seconds, giving a total amount of heat,

$$30097 \text{ joules.}$$

The smaller current was flowing for 9 minutes, giving

$$125.47 \times 9 = 1129 \text{ joules}$$

Hence the total heat supplied by the current is,

$$30097 + 113 = 30210 \text{ joules.}$$

Calculations for Part III.

Change in temp. per min at 2:45 = .000

Temp. at 2:45	=	.148
" " 2:59	=	.290
Change in temp	=	.142

Temp. at 2:59 = .290
" " 3:07 = .282
Change in temp = .008
" " " per min = .0010

Mean " " " " " = .0005

" " " " during 14 min = .007

Change in temp. due to current = .149

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Change in temp per min = .0010

Temp. at 3:15	=	.275
" " 3:29	=	.405
Change in temp	=	.130

Temp. at 3:29 = .405
" " 3:38 = .388
Change in temp = .017
" " " per min = .0019

Mean " " " " " = .00145

" " " " during 11 min = .016
" " " " " 3 " = .004

" " " " " 14 " = .020

Change in temp. due to current = .150

In this determination of the heat capacity with water, the same small current was used, it being allowed to flow for ten minutes each of the two times. The heat generated is then.

125.47 joules

The change in temperature produced by this heat is $0^\circ.149$ and $0^\circ.150$, giving a mean of $0^\circ.1495$ C. Hence,

$$\text{Joules per degree} = \frac{125.47}{.1495} = 839 \quad \text{(with water)}$$

Corrections for radiation, conduction, convection, stirring, etc.

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.

The "duration" of this experiment was 55 minutes, and the average temperature during this interval was + 0°.41 C. From the curve, the loss of heat at this temperature is 1.5 joules per minute. Hence the total loss of heat is

$$1.50 \times 55 = 83 \text{ joules.}$$

Weighting.

While the main part of this experiment is satisfactory, yet the duration was nearly an hour, and a direct determination of heat capacity was only made at the close of the experiment. The weighting is thus reduced to 2 points.

Summary of Experiment of Jan. 3rd.

Total heat supplied by the current = 30210 joules.

Initial temperature = -0.674.

" " corrected for zero = - .709.

Heat to raise calorimeter and contents from -.709 to 0 C

= 640 x .709 = 454 joules.

Final temperature = +0.159.

" " corrected for zero = +0.124.

Heat to raise calorimeter and contents from 0 C to +.124

= 839 x .124 = 104 joules.

Heat lost by radiation, conduction, convection, etc.,

= 83 joules.

Total correction = 454 + 104 + 83 = 641 joules.

Total heat required to melt 88.43 grams of ice.

= 30210 - 641 = 29569 joules

= 334.38 joules per gram of ice.

Experiment of Mar. 4th.

Part 1. heat capacity with ice.

The initial equilibrium temperature of this experiment was even higher than that of Mar. 3rd., and therefore the value of the heat capacity must be taken from the curve there given. The amount of ice used this time was 113.02 grams, of which the corresponding heat capacity is,

Joules per degree = 656. (with ice)

On the following page are the observations made during the period in which the ice was being melted. This is a straightforward experiment, all the ice being melted by the first application of the current, and the final equilibrium temperature being only a few tenths of a degree above 0°C.

Observations of the experiment of Mar. 4th.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
1:04	-.521		1:32	+.62	
05	.517		33	.65	
06	.513		34	.67	
07	.508		35	.74	
08	.504	Current on	36	.70	
09	.500	at 1:09:30	37	.74	
10	-.25		38	.75	
11	+.30		39	.80	
12	.33	Cell No.329	40	1.04	Current off
13	.35	Q = 10,000	41	1.04	at 1:40:35
14	.40	P = 1114	42	.65	
1515	.38	s = -0.55	43	.48	
16	.43		44	.41	
17	.45		45	.387	
18	.48		46	.377	
19	.45		47	.371	
20	.40		48	.367+	
21	.54		49	.367	
22	.45		50	.367	
23	.47		51	.367	
24	.49		52	.367	
25	.49		53	.367	
26	.50		54	.367	
27	.56		55	.367	
28	.57		56	.367	
29	.60		57	.367	
30	.55		58	.366-	
31	.66		59	.366	

Observations of the experiment of Mar. 4th.

Part III. Heat capacity with water.

Time	Temp.	
2:00	-.365	
01	.365	
02	.365	
03	.364	
04	.364	
05	.362	
06	.360	
07	.359	
08	.357	
0909	.357	
10	.355	
11	.354	
12	.352	
13	.351	
14	.350	
15	.349	
16	.348	
17	.347	
18	.346	
19	.345	
20	.344	Current on at 2:20:30
21	.	Current off at 2:21:02
22	1.043	
23	1.045	
24	1.029	Cell No. 329
25	1.015	ω = 10.000
26	1.005	P = 1114
27	.996	
28	.987	
29	.979	
3030	. .971	
31	.963	
32	.956	

Calculations for Part II.

The current was measured in terms of the standard cell No. [illegible] (1.0193 volts), and is therefore,

$$\frac{1.0193}{.500[illegible]} = 2.03827 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with $P = 1114 = 1114.82$ ohms, this value giving a mean deflection of -0.55 division, corresponding to -0.07 ohm. Hence the value of P which would have given an exact balance is 1114.75 ohms. This gives,

$$1.0193 \, \frac{11064.4}{1114.75} = 10.1170 \text{ volts.}$$

The current through the potentiometer circuit is,

$$0.00091 \text{ ampere,}$$

giving for the current in the heating coil,

$$2.03827 - 0.00091 = 2.03736 \text{ amperes.}$$

This current was flowing for 1865 seconds, giving a total amount of heat,

$$38441 \text{ joules.}$$

Calculations for Part III.

Temp. at 2:10 = .355
" " 2:20 = .344
Change in temp = .011
" " " per min = .0011

Temp. at 2:20 = .344
" " 2:26 = 1.005
Change in temp = .661

Temp. at 2:26 = 1.005
" " 2:32 = .956
Change in temp = .049

" " " per min = .0032 at 0.98
= .0036 at 1.03

Mean " " " " " = .0048

" " " " during 2 minutes = .0096
" " " " " 4 " = .0344

" " " " " 6 " = .044

Change in temp. due to current = .705

The current employed in this part of the experiment was the same as in Part II., and was allowed to flow 32 seconds. The heat generated is then.

$$10.1170 \times 2.03736 \times 32 = 660 \text{ joules.}$$

The change in temperature produced by this heat being 0.705.

$$\text{Joules per degree} = \frac{660}{.705} = 935. \quad \text{(with water)}$$

Corrections for radiation, conduction, convection, stirring, etc.

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.
The "duration" of this experiment was 39 minutes, and the average temperature during this interval was + 0.52 C. From the curve, the loss of heat at this temperature is 2.00 joules per minute. Hence the total loss is

$$2.00 \times 39 = 78 \text{ joules.}$$

Weighting.

In this experiment the first application of the current was sufficient to melt all the ice, the duration was short and the heat capacity was determined at the close. Therefore the weighting is expressed by 4 points.

Summary of Experiment of Mar. 4th.

Total heat supplied by the current = 38441 joules.

Initial temperature = -0.500

" " corrected for zero = -0.535.

Heat to raise calorimeter and contents from -.535 to 0 C

= 656 x .535 = 351 joules.

Final temperature = +0.367

" " corrected for zero = +0.332.

Heat to raise calorimeter and contents from 0 C. to +.332

= 935 x .332 = 310 joules.

Heat lost by radiation, conduction, convection, etc.,

= 78 joules.

Total correction = 351 + 310 + 78 = 739 joules.

Total heat required to melt 113.02 grams of ice.

= 38441 - 739 = 37702 joules.

= 333.59 joules per gram of ice.

Experiment of Mar. 5th.

Observations of the experiment of Mar. 5th.

Part 1. Heat capacity with ice.

Time	Temp.	
12:59	-.758	
1:00	.752	
01	.747	
02	.738	
03	.734	
04	.729	
05	.723	
06	.717	
07	.713	
08	.708	
09	.703	Current on at 1:09:30
10	.697	
11	.672	
12	.655	
13	.635	
14	.618	
15	.600	
16	.582	
17	.563	
18	.547	
19	.530	Current off at 1:19:30
20	.515	
21	.512	
22	.505	
23	.501	
24	.498	
25	.495	
26	.492	
27	.489	
28	[illegible]	
29	[illegible]	
30	[illegible]	
31	[illegible]	
32	[illegible]	
33	.472	

Observations of the experiment of Mar. 5th.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
1:34	-.469		2:02	+.82	
35	.466		03	.95	
36	.463		04	1.00	
37	.461		05	1.05	
38	.453		06	1.05	
39	.451		07	1.02	
40	.448		08	1.00	
41	.445		09	1.00	
42	.443		10	1.16	Current off
43	.440		11	1.28	at 2:10:40
44	.437		12	.92	
45	.433	Current on	13	.50	
46	-.20	at 1:45:30	14	.36	
47	+.40		15	.29	
48	.50		16	.27	
49	.60	Cell No.228	17	.248	
50	.45	Ω = 10,000	18	.232	
51	.55	P = 1113	19	.228	
52	.55	d = +2.60	20	.220	
53	.55		21	.213	
54	.58		22	.208+	
55	.63		23	.208	
56	.63		24	.207	
57	.75		25	.207	
58	.70		26	.207	
59	.71		27	.206	
2:00	.73		28	.206	
01	.75		29	.205	

Observations of the experiment of Mar. 5th.

Part III. Heat capacity with water.

Time	Temp.		Time	Temp.	
2:30	+.206		2:49	-.830	
31	.205		50	.822	Cell No.228
32	.207		51	.810	Q = 10,000
33	.206		52	.802	R = 1114
34	.206		53	.797	
35	.207		54	.789	
36	.207		55	.785	
37	.207		56	.777+	
38	.207		57	.772	
39	.207		58	.768	
40	.207		59	.765	
41	.207		3:00	.760	
42	.207		01	.755	
43	.207		02	.752	
44	.207		03	.747	
45	.207	Current on	04	.742	
46	.207	at 2:46:15	05	.738	
47	.600	Current off	06	.736	
48	.875	at 2:46:45	07	.733	

Calculations for Part I.

Temp. at 12:59 = -.758
" " 1:09 = .703

Change in temp. = .055

" " " per min = .0055

Temp. at 1:09 = -.703
" " 1:23 = .501

Change in temperature
= .202

Temp. at 1:23 = -.501
" " 1:33 = .472

Change in temp. = .029

" " " per min = .0029

Mean " " " " " = .0042

" " " " during 11 min = .046
" " " " " 3 " = .009

" " " " " 14 " = .055

Change in temp. due to current = .147

In this experiment the amount of oil used in the calorimeter was increased from 200 cc. to 300 cc. in order to introduce some variation in heat capacity, rate of cooling, etc. Altho the equilibrium temperature was not as low as would have been desirable for a determination of heat capacity, yet in view of the fact that the heat capacity had been changed so greatly by the addition of more oil, such a determination was made. The same small current was used, it being allowed to flow for ten minutes as usual. The rise in temperature, as shown on the preceding page, is 0.147, giving,

$$\text{Joules per degree} = \frac{125.47}{0.147} = 853 \quad \text{(with ice)}$$

Calculations for Part II.

The current was measured in terms of the standard cell No. [illegible] (1.0192 volts), and hence is,

$$\frac{1.0192}{.50008} = 2.03807 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with P = 1113 — 1113.79 ohms, this value giving a mean deflection of + 3.60 divisions, corresponding to +0.45 ohm. Hence the value of P which would have produced an exact balance is 1114.24 ohms. This gives,

$$1.0192 \, \frac{11063.9}{1114.24} = 10.1202 \text{ volts.}$$

The current through the potentiometer coils is,

0.00091 ampere,

giving for the current through the heating coil

$$2.03807 - 0.00091 = 2.03716 \text{ amperes.}$$

This current was flowing for 1510 seconds, giving a total amount of heat of,

31131 joules.

Calculations for Part III.

Change in temp. before 2:46 = 0 .

Temp. at 2:46 = .207
" " 2:56 = .777

Change in temp = .570

Temp at 2:56 = .777
" " 3:06 = .736

Change in temp = .041

" " " per min = .0041

Mean " " " " " = .0021

" " " " during 1 min = .0021
" " " " " 9 " = .0369

" " " " " 10 " = .039

Change in temp due to current = .609

The current was the same as used for melting the ice, and was allowed to flow for 30 seconds. The heat produced is

10.1202 x 2.03716 x 30 = 618 joules.

hence,

$$\text{Joules per degree} = \frac{618}{.609} = 1016 \text{ (with water)}$$

Corrections for radiation, conduction, convection, stirring, etc.

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.

The duration of this experiment was 37 minutes, and the average temperature during this interval was + 0.81 C. From the curve, the loss of heat at this temperature is 2.20 joules per minute. Hence the total loss of heat is,

$$2.20 \times 37 = 81 \text{ joules.}$$

Weighting.

In this experiment all of the factors taken into consideration in weighting are present, and therefore it is given the full value of 6 points.

Summary of Experiment of Mar. 5th.

Total heat supplied by the current = 31131 joules.

Initial temperature = -0.433

" " corrected for zero = -0.468.

Heat to raise calorimeter and contents from -.468 to 0 C

= 853 x .468 = 399 joules.

Final temperature = + 0.208.

" " corrected for zero = +0.173

Heat to raise calorimeter and contents from 0 C. to +.173

= 1016 x .173 = 176 joules.

Heat lost by radiation, conduction, convection, etc.,

= 81 joules.

Total correction = 399 + 176 = 81 = 656 joules.

Total heat required to melt 91.07 grams of ice.

= 31131 - 656 = 30475 joules.

= 334.63 joules per gram of ice.

Experiment of Mar. 6th.

Observations of the experiment of Mar. 6th.

Part I. Heat capacity with ice.

Time	Temp.		Time	Temp.	
1:15	-1.164		1:44	-.841	
16	.155		45	.835	
17	.149		46	.830	Current on
18	.143		47	.822	at 1:46:30
19	.136		48	.803	
20	.127		49	.784	
21	.120		50	.767	
22	.113		51	.750	
23	.105		52	.730	
24	.097		53	.713	
25	.091	Current on	54	.697	
26	.080	at 1:25:30	55	.678	Current off
27	.055		56	.665	at 1:55:30
28	.036		57	.660	
29	1.014		58	.656	
30	.995		59	.653	
31	.974		2:00	.650	
32	.953		01	.646	
33	.933		02	.643	
34	.914		03	.640	
35	.894	Current off	04	.636	
36	.880	at 1:35:30	05	.633	
37	.876		06	.630	
38	.871		07	.626	
39	.865		08	.623	
40	.861		09	.620	
41	.855				
42	.851		Stirring continued.		
43	.846		No readings taken.		

Observations of the experiment of Mar. 8th.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
2:17	-.583		2:46	+.93	
18	.580		47	.94	
19	.577		48	.98	
20	.573		49	1.07	
21	.570	Current on	50	1.20	Current off
22	-.25	at 2:21:30	51	1.02	at 2:50:15
23	+.30		52	.82	
24	.33		53	.73	
25	.35	Cell No.329	54	.728+	
26	.40	ω = 10,000	55	.728	
27	.35	P = 1114	56	.728	
28	.42	d = -1.83	57	.728	
29	.48		58	.728+	
30	.40		59	.726	
31	.65		3:00	.723-	
32	.53		01	.718	
33	.65		02	.715	
34	.71		03	.713	
35	.63		04	.708	
36	.73		05	.704	
37	.75		06	.700	
38	.83		07	.696	
39	.90		08	.692	
40	.81		09	.688	
41	.75		10	.684	
42	.74		11	.680	
43	.81		12	.677	
44	.89		13	.673	
45	.85				

Observations of the experiment of Mar. 6th.

Part III. Heat capacity with water.

Time	Temp.		Time	Temp.
3:14	+.669			
15	.665			
16	.660			
17	.66[illegible]			
18	.658			
19	[illegible]			
20	.846	Current on at 3:10:20		
21	.840	Current off at 3:20:35:		
22	.932			
23	.932	Cell No. 229		
24	.925	Q = 10,000		
25	.913	P = 1114		
26	.910			
27	.904			
28	.899			
29	.891			
30	[illegible]			
31	[illegible]			
32	[illegible]			

Calculations for Part I.

Temp. at 1:16 = -1.164
" " 1:26 = -1.091
Change in temp = .073
" " " per min = .0073

Temp. at 1:26 = -1.091
" " 1:37 = .876
Change in temp = .215

Temp. at 1:37 = .876
" " 1:46 = .830
Change in temp = .046
" " " per min = .0051
Mean temp per min = .0062
" " " " during 11 min = .068
" " " " " $\frac{1}{12}$ " = .005
" " " " " 12 " = .073

Change in temp. due to current = .142

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Change in temp. per min = .0051

Temp. at 1:46 = .830
" " 1:58 = .656
Change in temp = .174

Temp. at 1:58 = .656
" " 2:09 = .628
Change in temp = .028
" " " per min = .0025
Mean " " " " " = .0042
" " " " during 10 min = .042
" " " " " $\frac{2}{12}$ " = .007
" " " " " 12 " = .048

Change in temp. due to current = .126

$126 \times \frac{10}{9} =$ .140

The same amount of oil (300 cc.) was used in this experiment as in the preceding, but with a different calorimeter. This calorimeter was similar to to the other, weighing three grams less and not having quite as bright a surface thus giving a different radiation constant. Two determinations of heat capacity with ice were made, giving a change in temperature of 0.142 in the first instance with the current on ten minutes, and 0.126 for nine minutes of the current, which is equivalent to 0.140 for ten minutes of the current, or 125.47 joules. Hence,

$$\text{Joules per degree} = \frac{125.47}{0.141} = 890 \text{ (with ice)}$$

Calculations for Part II.

The current was measured in terms of the standard cell No. 229 (1.0193 volts), and hence, is,

$$\frac{1.0193}{.50008} = 2.03827 \text{ amperes}$$

The nearest balance of the potentiometer was obtained with P = 1114 = 1114.82 ohms, this value giving a mean deflection of - 1.33 division, corresponding to - 0.23 ohm. Hence the value of P which would have produced an exact balance is 1114.59 ohms. This gives

$$1.0193 \frac{11064.3}{1114.59} = 10.1174 \text{ volts.}$$

The current through the potentiometer coils is,

$$0.00091 \text{ ampere,}$$

giving for the current through the heating coil.

$$2.03827 - 0.00091 = 2.03736 \text{ amperes.}$$

This current was flowing for 1725 seconds, giving a total amount of heat of,

$$35560 \text{ joules.}$$

Calculations for Part III.

Temp. at 7:14 = .669
" " 7:10 = .646
Change in temp. = .023
" " " per min = .0038

Temp. at 7:20 = .646
" " 7:26 = .910
Change in temp = .264

Temp. at 7:26 = .910
" " 7:32 = .874
Change in temp = .036
" " " per min = .0060

Mean " " " " " = .0049

" " " " during 1 min = .0049
" " " " " 5 " = .0300
" " " " " 6 " = .035

Change of temp. due to current = .299

The current was the same as used for melting the ice, and was allowed to flow for 15 seconds. The heat produced was,

$$2.03736 \times 10.1174 \times 15 = 309 \text{ joules.}$$

Hence,

$$\text{Joules per degree} = \frac{309}{.299} = 1034 \text{ (with water)}$$

May 6th

Corrections for radiation, conduction, convection, stirring, etc.,

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.

The duration of this experiment was 33 minutes, and the average temperature during this interval was + 0°.68 C. From the curve the loss of heat at this temperature is 4.00 joules per minute. Hence the total loss is,

$$4.00 \times 33 = 132 \text{ joules.}$$

Weighting.

This experiment falls behind the first one only in the fact that at the close it was a few minutes before the rate of cooling became definitely established. In weighting, therefore, it is given the value of 5 points.

Summary of Experiment of Mar. 6th.

Total heat supplied by the current = 35560 joules.

Initial temperature = -0.570

" " corrected for zero = -0.605

Heat to raise calorimeter and contents from -.605 to 0 C

= 890 x .605 = 538 joules.

Final temperature = +0.728

" " corrected for zero = +0.693

Heat to raise calorimeter from 0 C. to +.693

= 1034 x .693 = 716 joules.

Heat lost by radiation, conduction, convection, etc.,

= 132 joules.

Total correction = 538 + 716 + 132 = 1386 joules.

Total heat required to melt 102.28 grams of ice

= 35560 - 1386 = 34174 joules.

= 334.12 joules per gram of ice.

Experiment of Mar. 7th.

Part 1. Heat capacity with ice.

On this day the smaller amount of oil (250 cc.) was used, but with the second calorimeter. The initial equilibrium temperature was too high to permit a direct determination of heat bapacity, but as the quantity of oil is the same as in the ealier experiments the curve there established is applicable here. The heat capacity corresponding to 85.92 grams of ice is then.

Joules per degree = 638 (with ice)

Observations of the experiment of Mar. 7th.

Part II. Melting the ice.

Time	Temp.		Time	Temp.	
2:00	-.404		2:35	+.85	
01	.394		36	.88	
02	.391		37	.90	
03	.388		38	.95	Current off
04	.385		39	1.02	at 2:39:30
05	.		40	.50	
06	.382		41	.25	
07	.380		42	.12	
08	.378		43	.05	
09	.375		44	.70	Current on
10	.372		45	1.03	at 2:43:00
11	.369		46	.50	Current off
12	.367		47	.23	at 2:45:00
13	.		48	.90	Current on
14	.363		49	1.48	at 2:47:00
15	.361		50	1.45	Current off
16	.359		51	1.425	at 2:48:25
17	.357		52	1.410	
18	.354	Current on	53	1.397	
19	-.05	at 2:18:30	54	1.384	
20	+.46		55	1.367	
21	.50		56	1.353	
22	.65		57	1.345	
23	.48		58	1.333+	
24	.51	Cell No. 328	59	1.321	
25	.50	Q = 10,000	3:00	1.310	
26	.56	P = 1114	01	1.300	
27	.62	d = -1.90	02	1.287	
28	.60		03	1.280	
29	.64		04	1.270	
30	.70		05	1.260	
31	.73		06	1.250	
32	.64		07	1.240	
33	.69		08	1.230	
34	.86				

Calculations for Part II.

The current was measured in terms of the standard cell No. 598 (1.0192 volts), and hence is,

$$\frac{1.0192}{.50008} = 2.03807 \text{ amperes.}$$

The nearest balance of the potentiometer was obtained with P = 1114 - 1114.82 ohms, this value giving a mean deflections of - 1.90 divisions, corresponding to -0.24 ohm. Hence the value of P which would have produced an exact balance is 1114.58 ohms. This gives,

$$1.0192 \ \frac{11064.3}{1114.58} = 10.1175 \text{ volts.}$$

The current through the potentiometer coils is

0.00091 ampere,

giving for the current through the heating coil,

2.03807 - 0.00091 = 2.03716 amperes.

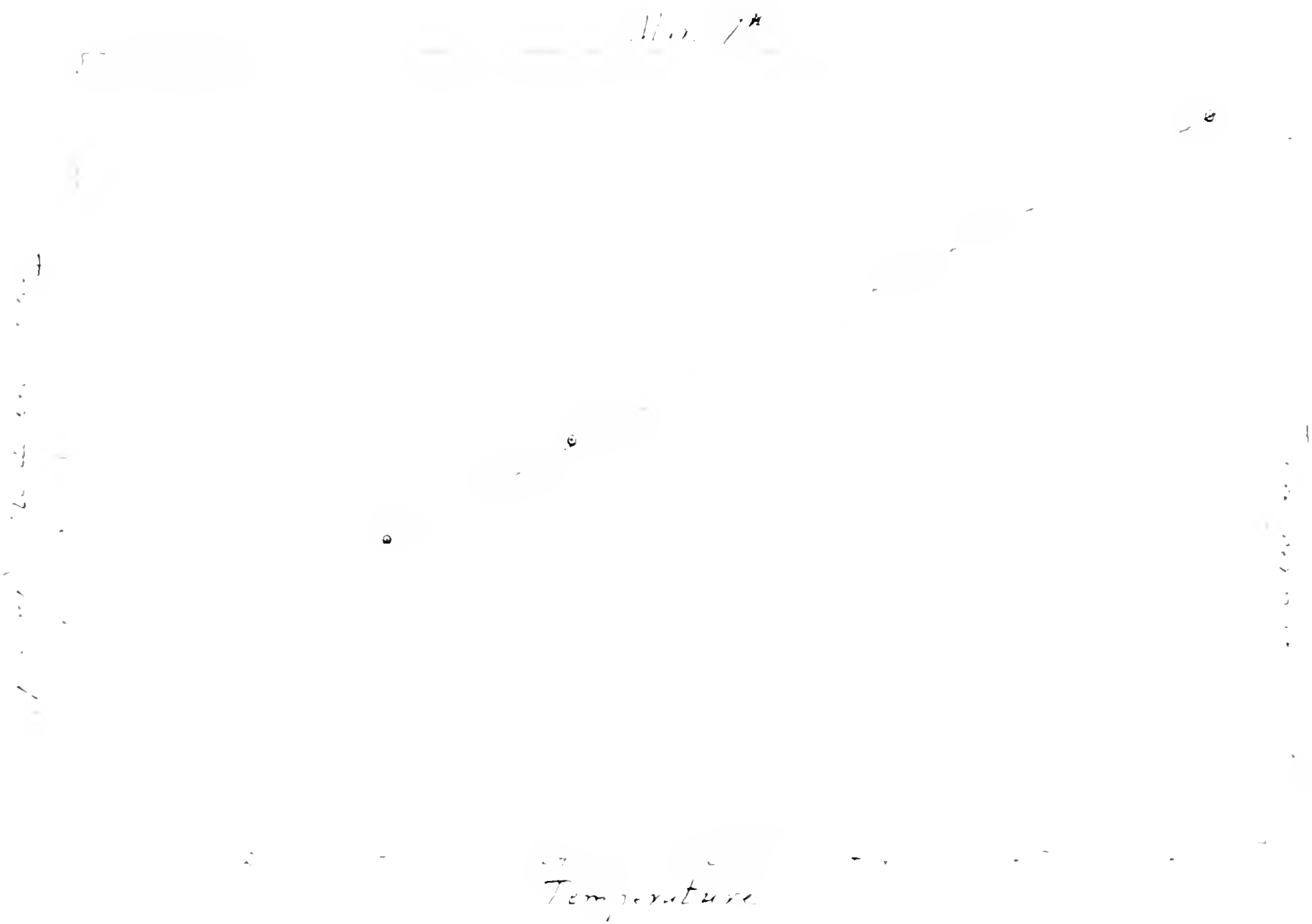
This current was flowing for 1465 seconds in all. When it was first taken off some ice remained unmelted and it was therefore put on again. The total amount of heat is,

30195 joules.

Part III. Heat capacity with water.

The final equilibrium temperature was too high to allow taking a direct determination of heat capacity with water. However, the conditions of the experiment were very like those of Mar. 2nd. and 3rd., the amount of ice used being about a mean between the amounts used on those days. Therefore no great error can be introduced by taking the heat capacity as the mean of the heat capacities determined for those experiments. That is,

Joules per minute = 832 (with water)


Temperature

Correction for radiation, conduction, convection, stirring, etc.

The rates of cooling determined at different temperatures are plotted on the adjoining sheet in terms of joules per minute.

The duration of this experiment was 40 minutes, and the average temperature during this interval was + 0°.80 C. From the curve the loss of heat at this temperature is 4.00 joules per minute. Hence the total loss is,

4.[illegible] x 40 = 160 joules.

Weighting.

In this experiment the duration was short, and the rate of cooling at the end was perfectly definite. The weighting it receives is therefore 3 points.

Summary of Experiment of Jan. 7th.

Total heat supplied by the current = 30195 joules.

Initial temperature = -0.354

" " corrected for zero = -0.389

Heat to raise calorimeter and contents from -.389 to 0 C

= 638 x .389 = 248 joules.

Final temperature = +1.333

" " corrected for zero = +1.298

Heat to raise calorimeter and contents from 0 C. to 1.298

= 832 x 1.298 = 1080 joules.

Heat lost by radiation, conduction, convection, etc.

= 160 joules.

Total correction = 248 + 1080 + 160 = 1488 joules.

Total heat required to melt 85.92 grams of ice

= 30195 - 1488 = 28707 joules.

= 334.12 joules per gram of ice.

SUMMARY.

In the following table is given a summary of the principal facts in the preceding experiments. All of the determinations are seen to agree closely with the mean, the greatest variation being for the experiment of Mar. 4th. There is nothing to indicate why this value comes out thus far from the mean.

The probable error of the weighted mean, calculated by the method of least squares, is 0.03 joule, thus giving for the final value of the heat of fusion of ice

$$334.21 \pm 0.03 \text{ joules.}$$

taking the value of the Clark cell as 1.434 volts.

If there is an error of 1 part in 1000 in the value of the Clark cell, it would alter this value of the heat of fusion of ice by 2 parts in 1000, since the electrical energy has been calculated from the formula <u>EIt</u>, and both <u>E</u> and <u>I</u> are determined in terms of the standard cell, the E.M.F. of which is expressed in terms of the Clark cell.

This result can be expressed in terms of mean calories if we take the value for a mean calorie to be 4.1832 joules, as determined by Reynolds and Moorby[1] and recently corroborated by Barnes[2]. This gives for the heat of fusion of ice

79.396 mean calories.

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[1] Reynolds and Moorby, Phil. Trans. vol.190, p.301, 1897.

[2] Barnes, Phil. Trans. vol.199, p.149, 1902.

Table IV. Summary of results.

Date	Total Joules	Total cor.	Cor. Joules	Weight of ice	Heat of Fusion	Weighting.
Feb. [illegible]	35[illegible]48	1366	33882	101.37	334.24	6
Feb. 28	35273	1033	34191	102.35	334.06	5
Mar. 2	27768	915	26348	80.23	334.69	3
Mar. 3	30210	641	29569	88.45	334.30	2
Mar. 4	38441	739	37702	113.02	333.59	4
Mar. 5	31131	656	30475	91.07	334.63	5
Mar. 6	35560	1386	34174	102.28	334.12	5
Mar. 7	30195	1493	28707	85.92	334.12	3

Weighted mean = 334.21

Probable error of " " = .03

This value for the heat of fusion of ice is somewhat lower than that obtained by Hess, and which appears the most trustworthy of previous determinations. However Hess stands alone in finding a value greater than 80 mean calories, or 336 joules, while the value here obtained is near the mean of all the previous determinations. It would be interesting to compare the heats of fusion of samples of ice prepared by different methods and of various degrees of purity. Some of the preliminary experiments with commercial ice seemed to indicate a slightly less heat of fusion, but these experiments will not warrant a more definite statement. However for this very pure ice, made as specified above, the value

334.01 joules

in terms of the Clark as 1.434 volts, will stand.

The writer's thanks are extended to Professor Ames for his interest and many helpful suggestions throughout this investigation. Valuable assistance has also been rendered by Mrs. Smith in that part of the work which required two observers.

Biographical Notes.

Arthur Whitmore Smith, S.B., M.Sc., was born in Hartford, Vermont, May 11, 1874. His early education was obtained in the district and village schools, and in 1890 he entered the New Hampshire College of Agriculture and the Mechanic Arts, receiving the degree of S.B. four years later. The following year was spent in graduate study at Cornell University. During the years 1894 - 1899 he was physical assistant in the nutrition investigations at Middletown, Conn. conducted by the Department of Agriculture. During this time he was also connected with Wesleyan University, first as a graduate student, receiving the degree of M.Sc. in 1895, and later as assistant in physics.

These positions were resigned in 1899 for graduate study at the Johns Hopkins University. 1900-1 he was instructor in physics and electrical engineering at Tulane University, and 1901-2, professor of electricity and electrical engineering at the University of Mississippi. 1902-3 he was fellow in physics at the Johns Hopkins University.

CERTIFICATES OF VERIFICATION.

As explained in the body of this paper, the standard cell and the standard half ohm coil were calibrated by the National Bureau of Standards immediately after they were used in this work. The particular resistances of the potentiometer circuit which were used in the measurement of the voltage were likewise calibrated. Copies of the certificates of verification are here given, and these values are used in the preceding calculations for the heat of fusion of ice.

(Copy)

Treasury Department
NATIONAL BUREAU OF STANDARDS
Washington.

April [illegible]-190[illegible].
Test No. [illegible].

CERTIFICATE OF VERIFICATION

of

Two Resistance Boxes

submitted by

A. [illegible]. Smith, [illegible] University.

-o-
Maker: Not stated.
Material: not stated.
-o-

Resistance in international ohms, at [illegible]°C.

Box of nominal value 10[illegible] ohms, including connecting wire.................9949.7

Box of nominal value 11[illegible]3 ohms 1113.79

Same box, plugs set for 1[illegible]4 ohms 1114.82

NOTE:- These values are correct to within [illegible]%.

(Signed) S.W.Stratton
Director.

(Copy)

Treasury Department
NATIONAL BUREAU OF STANDARDS
Washington.

April 28-190[illegible].
Test No.[illegible].

CERTIFICATE OF VERIFICATION

of

Resistance Standard No.[illegible]
Maker: Morris E.Leeds & Co., Philadelphia.

submitted by

A.W.Smith, Johns Hopkins University.

-:-

Material: Manganin
Nominal value: 0.5 ohm.

-:-

Temperature of oil bath.	Resistance.
[illegible]°.0 C.	0.5[illegible]08 international ohms.

when carrying a
current of [illegible].04 ampere.

The above value is based on the mean values of two coils belonging to the National Bureau of Standards, as redetermined at the Reichsanstalt in July, 190[illegible], and is correct to within two units in the fifth decimal place.

(Signed) S.W.Stratton
Director.

(Copy)

Treasury Department
NATIONAL BUREAU OF STANDARDS
Washington.

May 6-1907.
Test No.[illegible]

CERTIFICATE OF VERIFICATION

of

Cadmium Standard Cell No.329
Portable Type (with unsaturated cadmium sulphate solution)
Maker; Weston Electrical Instrument Co.

submitted by

A.W.Smith, Johns Hopkins University.

-o-

Temperature.	Electromotive Force.
18°C.	1.0193 international volts.

The above value is based on the mean value of ten standard Clark cells belonging to the National Bureau of Standards, taking the value of the Clark to be 1.434 international volts at 15°C., and the result is correct to within two units in the fourth decimal place.

(Signed) S.W.Stratton
Director.